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Analysis of the Emission Inspection Analyzer

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Ann Arbor, MI

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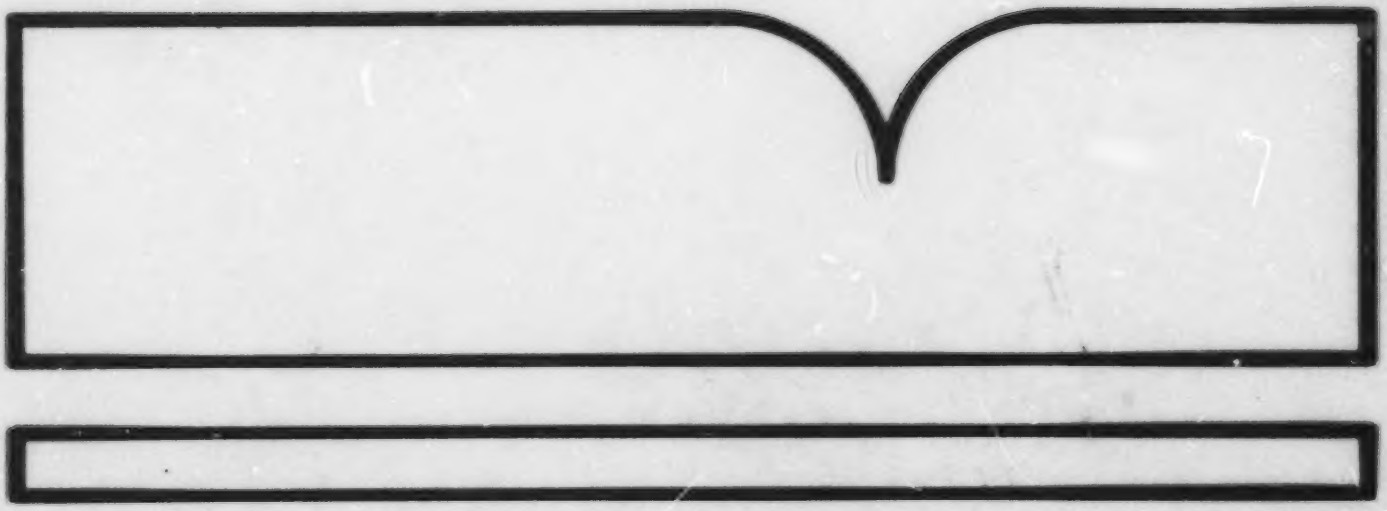

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16. ABSTRACT

Recently, there has been more emphasis on checking the performance of in-use vehicles. This is occurring through the implementation of state inspection and maintenance (I/M) programs as well as the forthcoming emission repair warranty regulations (207(b)) authorized by the Clean Air Act.

Practically all of the I/M data will be generated by field emission inspection analyzers (as opposed to laboratory equipment) in both centralized programs (i.e. central inspection lanes) and decentralized programs (i.e. inspection conducted by independent service centers). This data will affect the consumer through required maintenance, the automobile manufacturer through warranty claims, the State through emission credits, and the EPA through its ability to judge the effectiveness of the individual I/M programs. Obviously, a fundamental issue that an I/M program must deal with is the accuracy and validity of the test data taken under these programs. An inseparable part of that issue is the quality of the equipment used to obtain the data. Various state and trade associations have developed standards to control the quality of the equipment used, but as yet there are no nationally accepted minimum standards for inspection analyzers. An examination of the data validity issue should then encompass both -- Is the data generated under present conditions sufficiently valid?, and -- Is there a need for minimum quality standards for inspection analyzers? The subject of this report deals with these questions and issues.

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TECHNICAL REPORT

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EPA-AA-IMS-80-5-A

Technical Report
September, 1980

Analysis of the Emission Inspection Analyzer

by

William B. Clemmens

NOTICE

Technical Reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analyses of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position, or regulatory action.

Inspection and Maintenance Staff
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
U.S. Environmental Protection Agency

Note: This report is presented in two sections, -80-5-A, and -80-5-B. The first section (-A) contains Background, Technical Discussions, and Policy Information. The second section (-B) contains the Recommended Technical Specifications. The sections are available separately.

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The contributions and stimulating discussions with Merrill Korth and Gordon Kennedy of EPA during the formative stages of the technical specifications are greatly appreciated. The inputs and numerous reviews provided by the Equipment and Tool Institute Performance Test Group have greatly aided the preparation of this specification.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

EPA Recommended Instrument Specifications

The instrument used to measure motor vehicle exhaust concentrations of hydrocarbon (HC) and carbon monoxide (CO) is typically called a garage analyzer. This commonly used title has considerable significance to the I/M program administrator choosing a minimum specification for exhaust analyzers. The word "garage" indicates the location where the instrument is used. "Garage" also refers to its intended use: to assist in the diagnosis and repair of engines and emission control systems. As those familiar with diagnoses and repair using an exhaust analyzer know, the relative level of pollutants, and the change in emission levels in response to an adjustment or repair, are most important in servicing a vehicle.

The I/M program places a new burden on these instruments: inspection. An inspection of the vehicle's exhaust requires an accurate measurement of the pollutant concentration, not just a relative level. Whether a vehicle requires repair depends on this measurement, and accuracy becomes an important consideration. The instrument must provide a repeatable measurement in order to assure equitable inspection for each motorist. The failure to achieve repeatability inevitably results in challenges to the program's credibility.

The current garage type repair analyzer has been used as an inspection analyzer in currently operating I/M programs. In centralized I/M programs, its design capability has been greatly complemented by computer control and very frequent calibration and maintenance. It is continually under the watchful eye of an experienced instrument technician, and its working environment is often carefully controlled.

In decentralized I/M programs, the repair analyzer has also been used as an inspection tool, but with little consideration for its original intended use. The one concession to this situation has been periodic State checks of the instrument's calibration.

In the garage environment, the inability of the repair analyzer to provide accurate and repeatable measurements is well established. A recent NHTSA study indicated 32 percent of field use exhaust analyzers were reading more than 15 percent too high or too low. The study had attempted to use the industry standard of accuracy of ±3%, but found virtually no analyzer could meet this requirement. At ±5%, 93 percent of analyzers were inaccurate or not repeatable.

In addition, the performance specifications of repair analyzers often are inappropriate for inspection purposes. As an example, most instruments are designed to operate at 0 to 85% relative humidity. As an inspection analyzer, this could preclude use on high humidity days. In many areas of the country, this specification effectively limits the use of the instrument for a large portion of the year. This is of course an impractical constraint, yet the instrument manufacturers have done nothing to rectify this problem.

Several attempts to improve the inspection analyzer by establishing minimum specifications have been made. In 1974, the California Bureau of Automotive Repair (BAR) published its first minimum instrument specification applicable to garages participating in its Blue Shield inspection program. In 1980 BAR upgraded this specification. This year, the Equipment and Tool Institute (ETI), an industry organization, published its own specification, and has widely disseminated it to states preparing I/M programs. EPA has reviewed each of these specifications and finds them lacking in two areas: 1) failure to consider how the operator affects the measured results, and 2) specificity of accreditation test procedures.

Based on an error propagation model, EPA determined that the most important factor involving accurate exhaust measurements was proper operating procedures. EPA determined that incorrect gas spanning (calibration) could affect emission measurements by up to 40%, improper purging by up to 100%, leaks by 100%, and improper meter reading by 20%. Under the best of conditions, current equipment has a measurement accuracy of 25% to 35%.

The assessment indicated that minor, but important design changes could improve optimum accuracy to the 10 to 20 percent range. The improvements involve the detector, sample cell, and signal conditioning, and can be incorporated into existing designs with relative ease. EPA recommends that all states implementing centralized I/M programs adopt the EPA recommended specification for a manually operated analyzer. The specification, including detailed acceptance procedures, can be found in EPA-AA-IMS-80-5-B, "Recommended Specifications for Emissions Inspection Analyzers".

These improvements do not address the proper operation of the instrument. In centralized programs, this is dealt with through use of inspection personnel thoroughly familiar with the instrument, through recordkeeping and frequent calibration and maintenance, and often through real time computer control of the instrument.

In decentralized programs, the station operator or mechanic cannot be expected to become an instrument technician; the sophistication of the instrument precludes this. The cost pressures of completing the inspection as rapidly as possible encourage failure to provide proper calibration and leak checks. In fact, the calibration and maintenance requirements of these analyzers exceed those of any other garage instrument. Incompetence and fraudulent practices are also considerations in a decentralized program because of minimal inherent checks on the quality of the operation.

The advent of the $15 pocket calculator and the $800 home computer provides a practical solution to most of the problems of proper operation of the inspection analyzer in a decentralized I/M program. With the addition to each instrument of a small microcomputer, the inspection instrument can take on most of the calibration and recordkeeping burden. This computer operated analyzer will restrict operation until the unit is fully warm, will provide for automated gas span and leak checks, can accept vehicle ID and other information, will automatically make the pass/fail decision, will provide a hard copy output (which can include diagnostic information), and can store pertinent data on magnetic tape for future state analysis.

Such analyzers are not a wishful dream. One repair analyzer produced by Hamilton Test Systems incorporates some of these features and is commercially available. The New Jersey inspection program is currently evaluating a computerized unit produced by Sun Electric. New York State has recently contracted for over 4000 computerized analyzers for its decentralized I/M program. Given these recent developments, EPA's assessment of 9 to 18 months before quantities of units meeting its specification are available may be overly pessimistic.

EPA strongly recommends that each state implementing a decentralized I/M program adopt the EPA specification for a computer operated analyzer. The complete specification and detailed acceptance procedures can be found in EPA-AA-IMS-80-5-B ("Recommended Specifications for Emission Inspection Analyzers"). A drawing of an existing prototype follows this executive summary. EPA Report EPA-AA-IMS-80-5-A ("Analysis of the Emission Inspection Analyzer") provides considerable information on the need and benefits of adopting the computer operated analyzer.

Computerized features will increase the cost of the inspection analyzer. The attached report (EPA-AA-IMS-80-5-A) estimates that the full cost of the analyzer will be recovered for 2 to 3 dollars per test. In addition, the cost to the garage owner can be reduced through investment credits and depreciation. These considerations are fully discussed in the report. The estimated cost (1980 dollars) of the various types of analyzers is shown below.

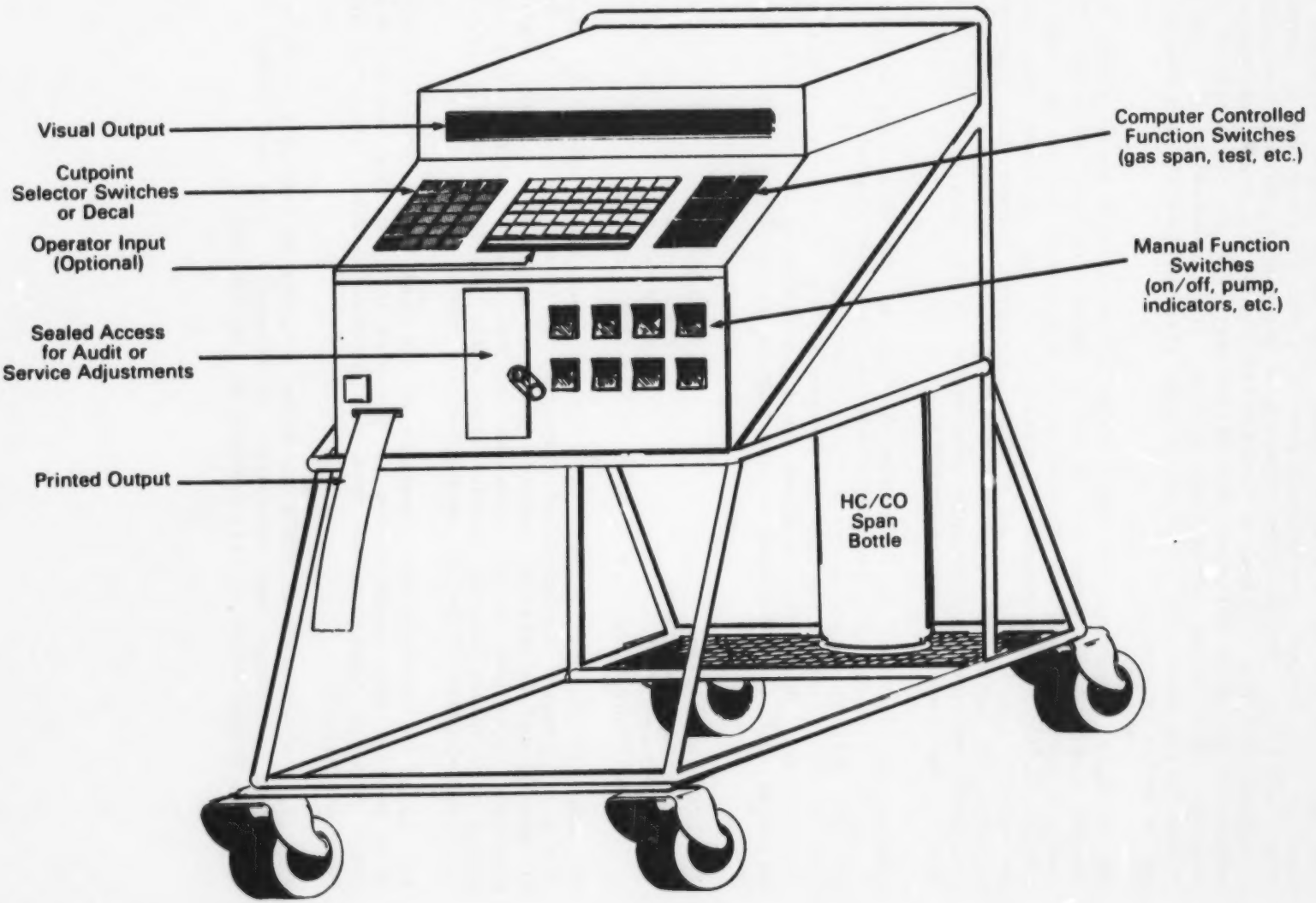
EPA computerized	$6195 to 7395
EPA manual operation	$4490 to 5690
BAR 80 certified	$3750 to 4950
Current Repair Analyzer (ETI)	$3000 to 3750

The computer operator analyzer will allow a reduced frequency of state audits of licensed decentralized inspection stations. Because of the instrument's self-calibration feature, quarterly audits will provide quality assurance equivalent to the otherwise required monthly audits. This provision will reduce program administration costs, and should be an incentive for State adoption of the EPA recommended analyzer.

The impact on implementation schedules of the lead time to procure instruments meeting this specification is discussed in a separate memorandum to EPA's Regional Administrators from the Assistant Administrator for Air, Noise and Radiation.

Finally, the I/M staff at EPA's Ann Arbor facility is available to provide additional assistance and information as necessary. You may contact Tom Cackette, Donald White, or Bill Clemmens at (313)668-4367.

COMPUTER OPERATED EXHAUST ANALYZER


Visual Output
Cutpoint Selector Switches or Decal
Operator Input (Optional)
Sealed Access for Audit or Service Adjustments
Printed Output
Computer Controlled Function Switches (gas span, test, etc.)
Manual Function Switches (on/off, pump, indicators, etc.)
HC/CO Span Bottle

TECHNICAL
REPORT

I. Introduction

It is doubtful that anyone would disagree with the statement that automobiles (and trucks) are part of the air pollution problem in the country. In the past, Congress has specified, through the Clean Air Act (and various amendments to the Act) that new cars must meet certain emission performance standards prior to the introducion of those vehicles into commerce. These performance standards have always been checked under closely controlled laboratory conditions with sophisticated equipment. The required accuracy and performance of this equipment has always been specified within the context of the laboratory situation.

Recently, there has been more emphasis on checking the performance of in-use vehicles. This is occurring through the implementation of state inspection and maintenance (I/M) programs as well as the forthcoming emission repair warranty regulations (207(b)) authorized by the Clean Air Act. Further, the new 1984 Heavy-Duty (HD) Truck Federal Regulations specify an idle standard as well as a driving cycle standard. Both the 207(b) warranty emissions test for hydrocarbons (HC) and carbon monoxide (CO), and the Heavy-Duty idle emission test for CO are expected to be conducted on in-use vehicles with data generated mostly by state-run I/M programs.

Practically all of the I/M data will be generated by field emission inspection analyzers (as opposed to laboratory equipment) in both centralized programs (i.e. central inspection lanes) and decentralized programs (i.e. inspection conducted by independent service centers). This data will affect the consumer through required maintenance, the automobile manufacturer through warranty claims, the State through emission credits, and the EPA through its ability to judge the effectiveness of the individual I/M programs. Obviously, a fundamental issue that an I/M program must deal with is the accuracy and validity of the test data taken under these programs. An inseparable part of that issue is the quality of the equipment used to obtain the data. Various state and trade associations have developed standards to control the quality of the equipment used, but as yet there are no nationally accepted minimum standards for inspection analyzers. An examination of the data validity issue should then encompass both — Is the data generated under present conditions sufficiently valid?, and — Is there a need for minimum quality standards for inspection analyzers?

If it is determined that minimum quality data is an objective, and minimum quality standards are needed, then it would be reasonable to investigate what those minimum standards should be. The determination of minimum standards presents several practical issues which include — Is such equipment available?, — What is the economic impact of such technology on society, on the equipment owner, and on the individual consumer?, and finally — How could such minimum inspection analyzer standards be best implemented?

The subject of this report deals with these questions and issues. Chapter II provides a brief summary of our conclusions and recommendations. Chapter III provides a discussion of the need for the States to establish minimum analyzer specifications. (EPA policy requires the State to establish a minimum instrument specification 4/.) Chapter IV details the analysis of

the technical issues pertaining to the inspection analyzer, provides a discussion of several economic issues, and provides overall recommendations based on the technical issues. The practical issues involved with State implementation of minimum analyzer specifications are also discussed in Chapter V. Chapters VI through X provide the specific recommended analyzer specifications, and Chapter XI provides specific evaluation test procedures that may be used to verify the performance of the equipment. References used in Chapters I through V may be found at the end of Chapter V.

II. Overview and Conclusions

The purpose of this study was to determine if an improved exhaust inspection analyzer was needed for use in Inspection and Maintenance programs, and to recommend a set of instrument specifications that could be adopted by the State as a minimum instrument requirement. The purpose of this report is to provide the States implementing I/M with EPA's recommendation for a minimum analyzer specification, and to set forth the benefits and issues surrounding State adoption of this specification.

Before any issues on analyzers could be discussed, it was found to be necessary to categorize the various types of field analyzers. This categorization process resulted in three distinct types of field analyzers -- 1) the centralized inspection analyzer, 2) the decentralized inspection analyzer, and 3) the repair analyzer. It is the two types of inspection analyzers (central and decentral) that are of concern. Therefore, the focus of the subsequent analyses in this document address only the inspection aspects or capabilities of field analyzers. The quality of, or minimum specifications for repair analyzers is left to market forces or specifications determined by trade associations, such as the Equipment and Tool Institute (ETI).

Data validity and the need for minimum quality inspection analyzer specifications were the first issues analyzed. The analysis investigated the basic functions for which the data will be used (i.e. pass or fail vehicles, etc.), and some consequences that may result if that data is incorrect. The status and condition of current in-use analyzers were evaluated, and the alternative of not specifying minimum requirements was discussed. Finally, policy precedents in other fields of emission measurement programs were reviewed for similarities.

Chapter III provides more detail on these analyses. Briefly the conclusion is: the accuracy of the test results is an important consideration in operating an effective I/M program. The consequences of bad data not only affect consumer protection, but affect the ability to judge the effectiveness of the programs. Both EPA and NHTSA studies indicate that there is substantial variation between in-use analyzers (up to 35%) 1/, and that a substantial number of analyzers in the field are inaccurate or not repeatable. One NHTSA study 2/ indicates that the number of analyzers in the field producing erroneous data is over 90 percent. From these data, the problems associated with no uniform specification, and the precedents of other programs, the staff concluded that some minimum specification on the quality of emission inspection analyzers was needed.

With a decision that a minimum specification was needed, the staff was faced with developing a technique that would allow a determination of the factors that should be included in a minimum specification. An error propagation

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1/ References to be found at the end of Chapter V, page 64.

model (described in Chapter IV) was developed that allowed such a determination. Several current analyzer specifications, most notably the State of California BAR 80 (Bureau of Automotive Repair), and the Equipment and Tool Institute (ETI) Recommendations were evaluated against this model. All of the specifications evaluated (including the two mentioned) were found to lack critical guidelines in two key areas: 1) control of the analyzer operator's procedures, and 2) detailed evaluation testing procedures. The lack of these guidelines in addition to concern on many specific technical requirements lead to the development of an EPA analyzer specification.

A draft of the EPA specifications was circulated to the equipment manufacturers for comment. Their comments were reviewed within the context of the considerations presented in this report. The final EPA analyzer specification recommends two distinct inspection analyzer types — a manually operated model, and a computer (microprocessor) operated model. The quality of the data generated by either type would be the same provided that the operator of the manual system followed correct procedures, checking frequencies, and maintained and reviewed log books to identify long term trends in equipment condition. These specific technical recommendations are found in Chapters VI through XI. Some of the more significant differences between these recommendations and other specifications are found in Table II-2 located at the end of this chapter. A generalized comparison between the EPA recommended specifications, the BAR 80 specifications, and the ETI recommendations can be found in Tables II-3, II-4, and II-5 also at the end of this chapter. A final comparison (Table II-6) between the EPA recommendations and 207(b) requirements follows Table II-5.

The staff recognized that the cost of the recommended equipment, and the possible economic burden on those purchasing such equipment would be an important influence on the final equipment recommendations. Sections E and F of Chapter IV review this issue in more detail. What the staff found was that inflation has increased the cost of current analyzers substantially. Analyzers that cost $2000 to $2500 in 1975, now cost $3000 to $3800 (see Table IV-8). Using those analyzers which meet the State of California BAR 74 specifications as a baseline, the staff determined that an average incremental retail price increase of a BAR 80 analyzer would be around $975. The estimated incremental retail price increase over the cost of a BAR 80 analyzer would be approximately $720 for the EPA manual system, and around $1700 for the computer system (See Table IV-11). Production quality audit testing for the EPA system is expected to increase the retail price by an additional $20. These estimated incremental price increases result in the estimated average retail prices presented in Table II-1.

Although some may claim that these equipment prices are prohibitive, the staff identified that the yearly amortized cost over a 5 year period represented a very small fraction of a centralized contractor fee or the yearly gross income for most service centers. Data taken from a recent DOT report to Congress 3/ indicate that the estimated retail price of $6850 for a computer inspection analyzer represented less than 2.5 percent of the yearly gross income for over 77 percent of the vehicle repair industry (paint and body shops excluded). The staff considered this burden on decentralized inspectors to be minor, but even this minor burden would be reduced rather substantially by the following real factors: depreciation credit on income

tax, first year investment credit on income tax, allocation of a portion of the inspection fee to defray the cost of the analyzer, and potential increases in business due to mandatory I/M vehicle repairs. Based on this limited economic study, the staff found no reason to alter the basic technical recommendations due to economics.

Table II-1

Specification	Estimated Average Retail Price (1980 dollars)
BAR 74	$3400
BAR 80	$4350
EPA Manual Operation	$5120
EPA Computer Operation	$6820

A factor that may concern some about the EPA recommendations is that one can not immediately purchase an inspection analyzer that meets these specifications. The technology to meet these specifications is readily available, and the manufacturers have estimated a 0 to 9 month delivery schedule for the manual system, and 9 to 18 months for the computer systems. One major manufacturer already markets a microprocessor based analyzer, and another major manufacturer has indicated it will do so shortly.

Practical issues such as the usefulness of analyzers currently in-use (grandfathering), and the availability of newer technology equipment dominated the final issue that was evaluated -- State adoption of the EPA specifications. The staff developed guidelines which could be used by a State to assure that some quality of grandfathered analyzers is maintained. Details of the guidelines can be found in Chapter V. The staff favors a phase-in/phase-out strategy to bring about an orderly transition to the newer technology. The phase-in portion of the plan could be implemented through purchasing policies. In this strategy any orders for new, replacement, or additional analyzers would only be issued for new technology analyzers. The phase-out portion of the plan would simply set a date beyond which older technology analyzers could not be used for inspection purposes. The date could be established based on the estimated 5 year useful life of the analyzer (see Chapter V).

The EPA staff strongly recommends the computer analyzer for decentralized programs (an example of a computer analyzer which EPA has purchased is shown in Figure II-1). This recommendation is in harmony with a recent report by Booz Allen to the California Legislature on I/M program options (March 21, 1980). For the decentralized option, the Booz Allen report concluded "...Foremost is the requirement that all decentralized inspection stations be equipped with a sophisticated analyzer that would be 'examiner proof.' ...".

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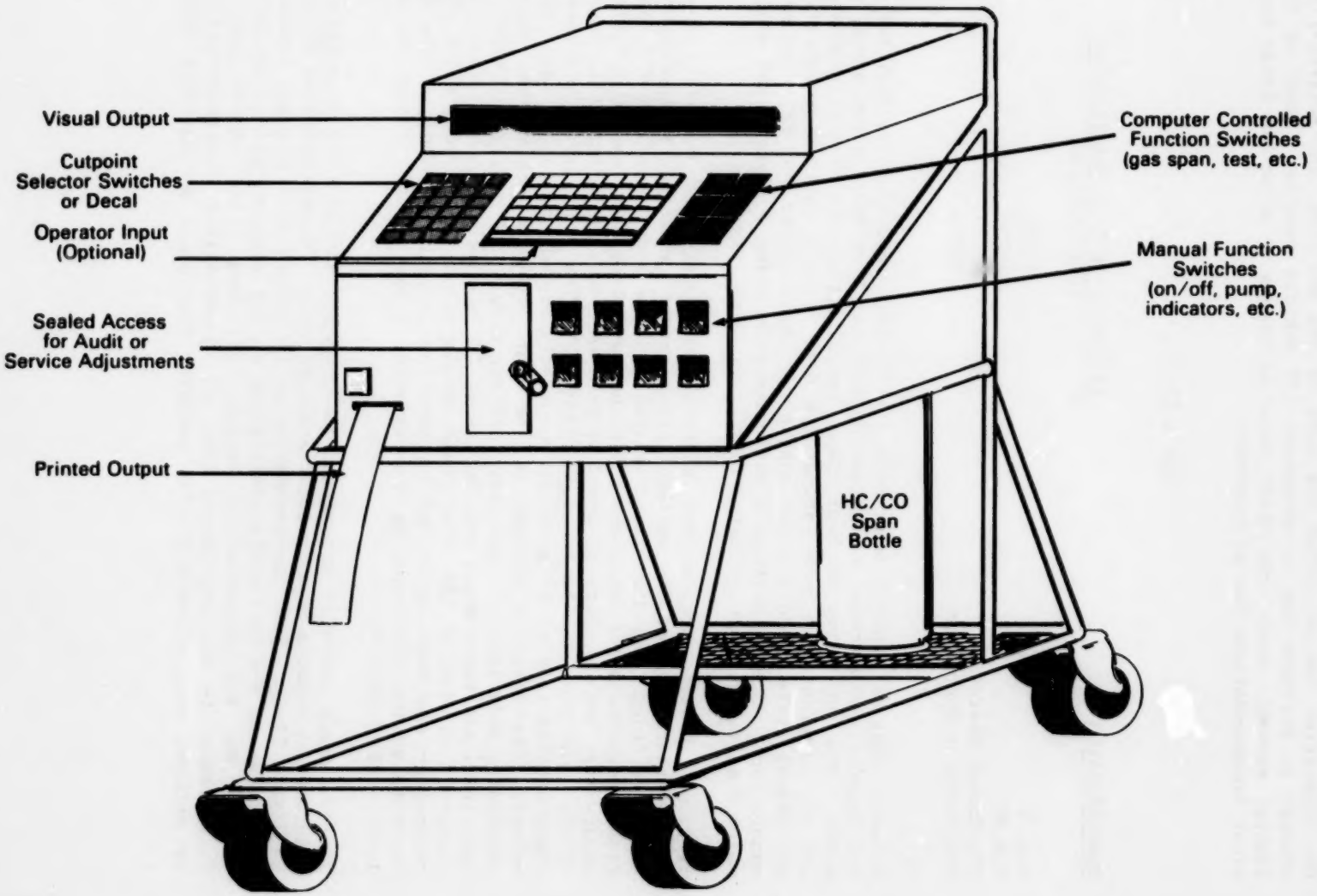

Visual Output
Cutpoint Selector Switches or Decal
Operator Input (Optional)
Sealed Access for Audit or Service Adjustments
Printed Output
Computer Controlled Function Switches (gas span, test, etc.)
Manual Function Switches (on/off, pump, indicators, etc.)
HC/CO Span Bottle

Figure II-1

Table II-2

Significant Features of the Technical Recommendations

A. Manual Operation Analyzers

1. Analyzer Calibration Curve: The analyzer calibration curve requirements are more statistically sound than other published specifications. Since the calibration curve sets the basic accuracy of the analyzer, it is important to measure the true performance when attempting to verify compliance to the specifications. Additionally these recommendations require better accuracy than other specifications at the 207(b) emission warranty levels of 220 ppm HC and 1.2% CO, and the Heavy-Duty idle standard of 0.47% CO.

2. Analytical Gases: All analytical gases must be traceable to National Bureau of Standards, Standard Reference Materials (SRMs), or an EPA Office of Mobile Source's approved standard.

3. Analyzer Spanning Concepts: Analyzer spanning is the process of adjusting the calibration curve into the proper frame of reference. True spanning involves the use of a known concentration analytical gas as a reference point when adjusting the analyzer.

An approximation of true spanning which is rather common on current field analyzers involves the application of a reference voltage level to the electronic circuitry. Known as electrical spanning, the reference voltage is supposed to be equivalent to the electrical signal that would be generated by a known analytical gas at that reference level, if that gas were introduced to the optical bench in the analyzer. The problem with the electrical span is that the voltage level used implicitly assumes that the relationship remains constant between the true gas signal and the reference level voltage. That relationship, in fact, does not remain constant, and is influenced by many factors. Some of these factors include barometric pressure, ambient temperature, sample temperature, system leaks, and the physical age or cleanliness of the optical bench.

The change in the relationship between the electrical span and true spanning (or gas spanning) can take place very rapidly from vehicle to vehicle, or it can take place over a long period of time as the analyzer slowly gets dirty. To account for changes in the analyzer's response to span gas, in a laboratory situation the analyzer is spanned before and after each test point (approximately every 5 to 20 minutes).

Gas spanning every 4 hours was recommended for field inspection analyzers as an optimum compromise between the necessary frequency of spanning and gas use. Based on the projected gas use, and the size of analytical gas cylinder recommended, span gas cylinders should last between 8 to 10 months. The average cost per vehicle of the span gas works out to be a fraction of a penny per vehicle. This recommended gas span check frequency compares to a

Table II-2 (continued)

once-per-week minimum requirement for 207(b) warranty coverage and a once-per-month proposed EPA policy minimum. Because the analyzer drift characteristics are only specified for a 1 hour period, an electrical span at least once each hour is recommended to cover the time duration between the 4 hour gas span checks.

Several practical options that would allow less frequent gas spanning and hence less use of the analytical gas are offered. For those units which incorporate features which will allow use of the less frequent gas spanning option, it is recommended that the minimum gas spanning frequency be at least once a week. Once a week gas spanning is a requirement for 207(b) warranty coverage.

4. Evaluation Tests: The recommended specifications provide detailed test procedures that can be used to evaluate the capabilities of a candidate analyzer. Including such test procedures avoids many of the problems associated with interpretation of a set of specifications. The tests are designed primarily for laboratory check-out of the candidate equipment. No other published instrument specification provides sufficiently detailed procedures that can assure unbiased equipment qualification.

5. Procedures: The recommended specifications require that the analysis system include all necessary equipment that will allow the operator to perform the necessary maintenance and testing procedures correctly. The manufacturers are allowed the flexibility to fit the procedures to their equipment, but specific functions that the procedures must address are required.

6. System Leak Checks: Leaks in the sample system are probably the source of the largest and most frequent errors that occur in emission measurement systems. This is because a leak is transformed directly into an error (i.e. a 15% leak is a 15% error). Most laboratories have rigid procedures for leak checking of analysis systems, and the process of searching for a leak can be very time consuming.

I/M analysis systems have special problems that the laboratory systems do not. First, laboratory systems are generally not moved around; I/M systems in decentralized systems are. Second, laboratories have special equipment to identify leaks, the expertise to use the equipment, and the knowledge to repair leaks inside the systems; the I/M operator generally does not have this knowledge available. Third, the laboratories generally have a strong commitment to prevent and repair leaks, and subsequently provide resources of time and money for this commitment; the independent decentralized inspector may not have this commitment, and may not be able to apply the resources to it. Fourth, the flow rates used in I/M systems are so small that even a 10% leak is difficult to measure without laboratory equipment, let alone a 2 or 3% leak.

Most other specifications do not provide for a routine leak check, and if they do provide for the necessary equipment, the equipment is usually a tapered tube flow meter, or the equipment to perform a vacuum decay test. A

Table II-2 (continued)

tapered tube flow meter is not practical for field use. It is a high maintenance item if built into the system, and tends to stick from a combination of hydrocarbons and water. This is true in a laboratory situation even with an extremely high filter changing frequency. If the flow meter is used to monitor system response time as well, the capacity of the flow meter is too large to read leaks without a 15-20% error in the reading. With the vacuum decay method, it is difficult to verify, in the field, the relationship between the vacuum decay time and the amount of emission measurement error. Further, the vacuum decay test is somewhat dependent on the gauge location in the system relative to the location of the leak, the gauge damping and protection, and the condition of the particulate filter(s) (i.e. a dirty filter has more pressure drop than a clean one). Primarily for these reasons, a flowing span gas leak check (through the sample line) is recommended on a weekly basis. (Such a check is also a requirement for the 207(b) warranty).

B. Computer Operated Analyzers

1. Quality: Same features as the manually operated analyzer.

2. Fail Safe Systems: The recommended specifications provide features that prompt and assist the operator in performing the necessary procedures required to obtain valid data. In many cases, these features are "one button" operations with the analyzer automatically performing the check.

C. Future Improvements

1. A discussion which provides manufacturers with long term goals for improvement of field analyzer technology has been included in this report. These recommendations have no impact on State adoption of the recommended specification in this report, but are provided to help stimulate major improvements in exhaust analyzers. These technology improvements would be desireable to be included in the basic recommended specifications, and could be implemented in the attached recommendations if the technology were less costly or widely available. For more information, see Chapter X.

Table II-3
Comparison of Operator Features
(overview)

Item	Purpose	EPA Recommendations: Computer Operation	EPA Recommendations: Manual Operation	BAR 80	ETI
I. Warm-up	Stabilize the analyzer performance parameters before use.	Time not specified, based on analyzer parameter, but analyzer cannot be operated until warm-up is achieved.	Same as computer analyzer.	15 min.	30 min.
II. Gas Span					
A. Equipment supplied	Allows operator to gas span.	Yes, integral system	Yes, integral system.	Yes, add on.	Optional add on.
B. Procedures	Tells operator how to gas span.	Automatically controlled by computer.	Supplied by MFG must meet minimum functional requirements.	Universal manual procedure	Supplied by MFG. no requirements.
C. Electrical Span Correction available to the operator.	Adjusts electronic span to track gas span.	Yes, Automatic	Yes, Manual	No	No
D. Range Correction available to Auditor.	Allows correlation between ranges.	Yes	Yes	No	No
E. Responsibility for frequency of Check.	Insure proper operation.	Automatically controlled by computer.	Controlled by operator (log book).	Controlled by operator (log book).	Not specified
III. Leak Check					
A. Equipment supplied for gas comparison.	Allows Auditor to quantify a leak.	Yes	Yes	No	No
B. Procedures	Tells operator how leak check.	Check automatically controlled by computer.	Supplied by MFG. and must meet minimum functional requirements.	No	No
C. Responsibility for frequency of field check.	Insure proper operation.	Automatically controlled by computer.	Controlled by operator (log book).	No	No

Table II-3 (continued)
Comparison of Operator Features
(overview)

Item	Purpose	EPA Recommendations: Computer Operation	EPA Recommendations: Manual Operation	BAR 80	ETI
IV. Field HC Hang-up Check	Prevents contamination from altering readings.	Yes, automatically controlled by computer.	Yes, test performed by the operator.	No	No
V. Test Value					
A. Time Averaged Tailpipe Sample	Provides more accurate, consistent results; prevents operation errors.	Yes	Yes	No	No
B. Determine Pass/Fail.	Prevents operator errors.	Yes	No	No	No
C. Results printed.	Provides consumer a receipt.	Yes	Optional	No	No
VI. Anti-Tampering	Prevents intentional altering of analyzer.	Yes	No	No	No

Table II-4
Comparison of Performance Specifications
(overview)

Item	EPA Recommendation	BAR 80	ETI
° Accuracy of Calibration Curve			
- High Scale	5% Read. @ 90% C.L.	3% fs	10% Read./5% Read
- Low Scale	5% Read. @ 90% C.L.	3% fs (L)	10% Read./5% Read
Temp. Range	35° - 110° F	35° - 110°F	35°-55°F/55°-85°F
° Accuracy of Audit Gases	1% Traceable to NBS Standard Reference Material (SRM). (MVEL procedure)	Traceable to California Standards. (L)	2% Traceable to N (Traceability pro cure not specifie
° Accuracy of Span Gases	2% Traceable to NBS SRM. (MVEL procedure)	Traceable to California Standards. (L)	2% Traceable to N (Traceability pro dure not specifie
° Drift			
- Zero	2% fs L.S. 1 hour	3% fs 2 hours	2.4-3% fs L.S. 1
- Span	2% fs L.S. 1 hour	3% fs 2 hours	3% Read. 1st hour 2% Read. 2nd hour
° HC Hang-Up	Less than 20 ppmh (5% fs L.S.) before each test.	Less than 200 ppmh (10% fs H.S.) in 15 sec. after 2 min. sample. For evaluation test only. (L)	Less than 200 ppm (10% fs H.S.) in 30 sec. after 1 m sample. For eval tion test only.
° Interferences			
- Gaseous	3 Items @ 1% each	6 Items @ 2.5% each (L)	5 Items @ 2.5% ea
- Electrical	6 Items @ 1% each	5 Items @ 2.5% ea.	no criteria speci
° Leaks	3% of comparative gas readings, weekly.	2.5% of reading for evaluation test, frequency of field check not specified. (L)	optional, no value specified.
° Operating Environment			
- Temperature	35° to 110°F	35° to 110°F	35° to 105°F
- Relative Humidity	0% to 100% (raining)	0 to 85% (L)	0 to 85% (L)

fs = full scale
H.S. = High Scale
L.S. = Low Scale
Read. = Analyzer reading
MVEL = EPA Motor Vehicle Emission Laboratory, Ann Arbor, Mich.
(L) = Less stringent than EPA recommendation.
(M) = more stringent than EPA recommendation.

Table II-4 (continued)
Comparison of Performance Specifications
(overview)

Item	EPA Recommendation	BAR 80	ETI
° Probe	16 inch with tailpipe extender.	12 inch with tail-pipe extender. (L)	Length not specified. (L)
° Propane/Hexane Conversion Factor	.48-.56 @ 90% C.L.	.500-.540 (M)	.46-.58 (L)
° Response Time	14 seconds to 95% of Reading	8 seconds to 90% of Reading (M)	10 seconds to 90% of Reading (L)
° Vehicle Check	Equivalency Test; precision, slope, and mean value comparisons.	Comparison test, no regression of of data. (L)	Test procedure or acceptance criteria not specified. (L)

fs = full scale
H.S. = High Scale
L.S. = Low Scale

Read. = Analyzer reading
MVEL = EPA Motor Vehicle Emission Laboratory, Ann Arbor, Mich.

(L) = Less stringent than EPA recommendation.
(M) = more stringent than EPA recommendation.

Table II-5
Comparison of Specification Features

Item	EPA Recommendation	BAR 80	ETI
° Automatic Data Collection Option	Yes	No	No
° Anti-tampering	Yes, computerized model	No	No
° Computer Control Specifications	Yes	No	No
° Evaluation Test Procedures	Yes	No	No
° Loaded Mode Option	Yes	No	No
° Production Line Audit Plan	Yes	Random Audit no limit*	No

* BAR Personnel Restricted on out-of-state travel. Travel policy negates audit plan.

Table II-6
Comparison of EPA Recommendations
versus 207(b) Minimum Specifications

Item	EPA Recommendations	207(b)
• Accuracy of the calibration curve		
- HC	5% of Reading	±15 ppmh @ 200 ppmh (7.5% of 200 ppmh)
- CO	5% of Reading	±0.1% @ 1% (10% of 1%)
• Drift		
- HC	2% fs L.S./1 hr.	±15 ppmh/1 hr. (3.75% fs L.S./1 hr.)
- CO	2% fs L.S./1 hr.	±0.1%/1 hr. (5% fs L.S./1 hr.)
• HC Hang-Up Check Frequency	Before each test	not required
• Leak Check		
- Type of test	gas comparison	gas comparison
- Tolerance	3% of Reading	3% of Reading
- Frequency	weekly	weekly
• Response Time	14 seconds to 95% of Reading	15 seconds to 95% of Reading
• Span Check Frequencies		
- Gas Span		
• Recommended	twice daily (4 hr intervals)	-
• Minimum	weekly	weekly
- Electrical Span		
• Minimum	1 hr interval	1 hr interval

III. Minimum Quality Analyzers —— Are They Needed?

A. Introduction

There appears to be many conceptions about what an emission analyzer is, and what it can and cannot do. Much of what an emission analyzer can do is related to the function for which it was designed. For instance, a laboratory analyzer is generally designed to be used within the controlled environment of the laboratory building, to be operated by knowledgeable scientists, engineers, or technicians, and to be maintained on a regular basis. Under these conditions the laboratory analyzer can perform the function for which it was intended —— precise emission measurements.

Currently, field emission analyzers were designed more as vehicle repair equipment than emission inspection equipment. The advent of the I/M programs along with the concept of centralized and decentralized inspection systems provides a challenge to the previous design goals for this equipment. In centralized programs, the function of the emission analyzer is mainly that of vehicle inspection. For that purpose, most programs expect a minimum level of quality of data from th equipment in terms of accuracy, repeatability, etc., and the design goals for this equipment are less subject to dispute. When implementing a decentralized program, however, the distinction between analyzer functions becomes blurred by the past history of the design philosophy used in the design of analyzers currently found in service centers (i.e. past history being that of repair, not inspection).

With the implementation of I/M programs, there now emerges three distinct types of field emission analyzers — 1) the centralized inspection analyzer, 2) the decentralized inspection analyzer, and 3) the repair analyzer. The quality of the inspection equipment and subsequent data should be the same for both centralized and decentralized programs. The repair analyzer will probably find the greatest use in centralized programs. Although some independent vehicle repair centers may opt for the more accurate decentralized inspection analyzer for repair work, it is suspected many will use the lower cost repair analyzer. Estimates suggest there may be as many as 5 to 10 repair analyzers for each inspection analyzer or inspection lane. The quality of these repair analyzers would, of course, be judged by the centralized inspection analyzer during the inspection or reinspection test. For the repair analyzer, the quality of the equipment, therefore, is probably best left to market forces (i.e. number of retests failed by the inspection analyzer), and the equipment specifications suggested by the ETI would be recommended for those analyzers. However, because the driving function for maintenance in an I/M program is the inspection, this report will focus on only the inspection function and capabilities of field analyzers.

The subject of this chapter deals with the issue of analyzer quality. Since analyzer quality is rarely an issue in centralized programs (i.e. most central programs choose the best quality analyzer available), the quality and capabilities of the decentralized equipment will receive the most emphasis. Because there has not yet been a widespread acceptance of the distinction between the function of a decentralized inspection analyzer, and a

decentralized repair analyzer*, an analysis of the quality of field analyzers must look at the inspection capabilities of equipment that was possibly designed for repair functions.

B. Uses of Test Data

In order to assess the importance of the validity of the data from the inspection analyzer, knowledge of the end use of that data would be beneficial. The immediate use of the data generated by the inspection analyzer would, of course, be to determine whether a vehicle passed or failed state inspection standards. The degree of failure would help determine the minimum level and type of vehicle maintenance required in order to pass, hence, the minimum cost to the consumer would to an extent be determined by the analyzer. The absolute value of the failure could also initiate the emission repair warranty provisions of Section 207(b) of the Clean Air Act. If a Heavy-Duty gasoline-fueled vehicle I/M program existed, the absolute value of a failure on 1984 and later model year vehicles could form the basis of a recall action. And finally, the number of vehicles failing would provide input into assessing the effectiveness of the I/M program.

On a qualitative basis, the uses of this data are important. To some extent the degree of importance of the data is based on the seriousness of the consequences due to incorrect or bad data.

C. Consequences of Bad Data

The consequences of bad data involve risks to the consumer, the automobile manufacturers, and the environment. When considering consumer protection, only errors of commission (reading high) are normally assumed to be a problem. Certainly, incorrectly high readings are a problem to the individual consumer. Data from a recent NHTSA study 2/ suggests at least 16 percent of the analyzers currently in the field read high by more than 15 percent. Near the lower cutpoint levels, some of the units tested read high by as much as 40 percent. Translated to the consumer's risk, this data suggests at least 16 percent of the public is in danger of receiving an incorrectly high assessment of their vehicle's emissions. The consumer is hurt in two ways by these high readings. First, his vehicle could fail the I/M test when it potentially should not have. The consumer is out both the time and effort involved in repairing a vehicle that potentially did not need repair, as well as the time and effort required for a retest. Secondly, the consumer will be out the money it cost for the potentially unneeded maintenance.

For the consumer, though, errors of omission (reading low) are just as important as errors of commission (reading high). Data from the same NHTSA study shows a parallel situation for instruments reading low. At least 16

* The Equipment and Tool Institute (ETI) publically proposed the same three classes of field emission analyzers (i.e. centralized inspection, decentralized inspection, and vehicle repair) in a presentation given at an APCA meeting in Detroit, Michigan, on April 23, 1980.

percent of the analyzers read low by more than 15 percent. But, in this case some of the analyzers tested read as much as 50 percent low. This data excluded the effects of leaks in the systems. Leaks could easily increase the magnitude and number of low reading analyzers. Low readings translate into a potential fuel economy penalty for the consumer. Even if the consumer's vehicle were to pass the I/M test, when it should have failed, such vehicles need repair or maintenance. Not getting proper repairs or maintenance when the vehicle needs it costs the consumer and the nation potential fuel economy savings.

Considering that at least 16 percent of the public is potentially affected by erroneously high readings, and at least 16 percent of the public is potentially affected by erroneously low readings, suggests that a significant portion of the public (32 percent) could be adversely affected by incorrect analyzer readings. These estimations are based on the data from the NHTSA study 2/ which looked at only one of several variables in emission measurement (see Chapter IV, Section B, Measurement Error Sources). If anything, these estimates on the omission and commission errors should be conservative. Even so, some may wish to comment that: "So what if some analyzers read high and some read low! They all balance out in the end!" Such statements assume that the consumer only gets hurt by high readings. So they conclude "Some people pay a little more and others get by without paying what they should." First, that is not a very equitable position to take; it must be remembered that the public consists of individuals. Generally, individuals are willing to pay their fair share if they believe that the costs are allocated in a fair manner. Individuals can be quite hostile if they believe that the costs are unfairly allocated. But, the more important point is that it is not only the high reading consumers that are unfairly penalized, but that the low reading consumers are also penalized. The real case is that erroneous analyzer readings cost everybody.

The automobile manufacturers need not be concerned about incorrectly low readings. Because of the 207(b) warranty repair provisions, the automobile manufacturers are concerned about errors of commission (high readings). Since the NHTSA data presented pertains to the analyzer characteristics, the characteristics would be expected to apply equally to analyzers measuring 207(b) vehicles. Under these conditions the manufacturer might challenge the State inspection program, or refuse to provide warranty repairs. The latter is assumed to be illegal, but the dissention created by the manufacturer may raise public concerns about the quality and fairness of the State program.

Such concerns may be exhibited by consumer "shopping" between inspection lanes or centers. For instance in the Oregon program, there is no inspection fee until the vehicle passes. There have been reports that consumers try many test lanes until they get the vehicle to pass instead of repairing the vehicle. Or, such concerns could esculate into local TV and newpaper exposés on the discrepencies in emission results between different testing lanes (or inspection centers).

In fact, adverse exposés need not be centered only on discrepencies in results, they could allege improper operation or use of the emission testing equipment, thus claiming any test results from the claimed improper operation would be void. Such a situation would more likely occur in a decentralized program if that program did not have a strong set of technical minimum specifications. Take humidity operating limit specifications for example. Much of the equipment currently in the field was not designed for accurate measurements under high ambient humidity conditions. The instrument specifications were designed to prevent warranty problems at high humidities, not for accuracy. Most specifications have a stated upper humidity limit of 85 percent relative humidity. The BAR 80 specifications also use this limit. The implication of this limit is that performing an inspection test at ambient humidities higher than 85 percent constitutes improper operation of the testing equipment. The consequences of this situation could mean that anytime it was raining during an inspection test, the validity of these tests could be challenged by the consumer or the automobile manufacturer.

Clearly, adverse publicity would provide the State I/M program some headaches. But without public belief that the program is credible, it is questionable that the program will survive as an effective program. This could be one of the most severe consequences of bad data.

D. Current Analyzers

Before making a determination on the necessity (or lack of) for minimum quality analyzer specifications, it is pertinent to discuss the condition and the capabilities of present analyzers. In the previous section, a recent NHTSA study was referenced. 2/ This study evaluated the accuracy and repeatability of various pieces of vehicle repair equipment (emission analyzers, timing lights, wheel balancers, etc.). The location of the equipment that was evaluated included mass merchandizers, dealerships, independent repair shops, service stations, specialty repair shops, and diagnostic centers. The specific locations across the nation were selected on a random basis to be statistically representative of the auto repair industry. The sites included States with and without in-use I/M programs.

The study indicated that only 16 percent of the emission analyzers tested were judged to be accurate. The word "judged" is used to indicate that the NHTSA study had to expand the accuracy criteria to ±5 percent from the industry accepted standard of ±3 percent. The 3 percent figure would have failed significantly more analyzers, possibly preventing any of the analyzers from being considered accurate.

In this study, accuracy was defined as the ability of the analyzer to read correctly both a high concentration (1576 ppmh, 8.05% CO) calibration gas, and a low concentration (307 ppmh, 1.62% CO) calibration gas. The gas was introduced through either a span port (if available) or through the probe. When introducing gas through the probe, precautions were taken to prevent leaks from affecting the accuracy determination. No determination of the number of systems with leaks was made, even though leaks are a significant source of measurement error.

The other test performed by the study measured the repeatability of the analyzers. In this test, the analyzer's capability to replicate readings of the same high and low calibration gases was observed. If it is required that those replicate readings be accurate (±5%) as well as repeatable, only 7 percent of the analyzers tested would be acceptable.

The statistical representativeness of the survey suggests that 93 percent of the analyzers currently in the field would fail at least one of the two rather simple tests on accuracy or repeatability. The staff considers this condition serious because as Chapter IV will point out, there are many factors other than calibration accuracy and repeatability that affect the ability of the analyzer to measure exhaust samples correctly.

The effects of some of these other factors were highlighted in a previous contract study on field analyzers (work performed by Olson Laboratories in 1976-1977). 5/ The following selected comments on these other factors from that study suggest that real world effects may substantially affect the ability of current field analyzers to accurately measure the true level of exhaust emissions.

1) "The operation of some HC/CO analyzers can be severely impaired by exposure to high temperature environments. In many cases, span and/or zero adjustment at high temperatures is insufficient for correct calibration. Typical failures appear to be a result of electronic malfunction due to overheating. Most instruments exhibiting malfunctions at

high temperatures will recover to normal when operated again at room temperature. Low temperature operation tends to cause the same type of problem but the incidence is much lower."

2) "Humidity variation affects the output of most HC/CO instruments. Variations of ±10 percent RH can cause a significant change in output level. Operation at high altitude causes malfunctions at high temperatures. The principle detrimental operational effect of high altitude is insufficient zero/span adjustment to achieve correct calibration. Altitude compensation has apparently not been successfully implemented by all manufacturers."

3) "The interference effects of various noninterest gases can be quite significant at specific temperatures, and carbon monoxide [ed. - presumed to be dioxide] are the most dominant interference gases. Some analyzers exhibit cross-sensitivity between their HC and CO channels."

4) "In general, most instruments showed response times of up to 30 seconds under extreme temperature and humidity conditions."

5) "In some cases, the response time was a function of the specific design or sampling operation of the instrument. The general trend in response time indicated a range from slightly less than 10 seconds to approximately 30 seconds for 100 percent final reading."

6) "Instrument zero drift at normal operating temperatures for a period of 4 hours, in many cases, can exceed ±3 percent of full scale. Temperature extremes generally serve further to degrade zero drift performance."

7) "Instrument warm up times at normal room temperature were generally less than 30 minutes. Most state specifications require 30-minute warm up times for all temperature and humidity conditions. Both high and low temperature tests indicated longer warm up times than those at 70°F for most instruments. Temperature-related drift at the extremes may account for the apparent increased warm up times by masking the warm up performance with meter drift."

8) "Prolonged loaded steady-state testing caused early filter degradation on some instruments. Water accumulation in some lines occurred during these tests. The water accumulation indicated, in general, that if an instrument is to be used for a significant time in loaded steady-state or high rpm testing, an auxiliary sample conditioning or water removal system should be utilized to achieve maximum instrument performance."

9) "Instrument durability in sampling service, demonstrated in the durability tests, ranged from early failure to completion of approximately 1,000 hours of exposure to exhaust gases. Long-term use under exhaust conditions generally resulted in repetitive filter replacement, sample system degradation and blockage, water accumulation and analyzer

> degradation resulting in loss of response, increased response times, increasing drift and instability. Analyzer and sample system designs were most accurately characterized by performance observation during durability tests."

In an effort to control the validity of inspection test data, the State of California maintains a monthly audit of service center inspection analyzers. This audit check only determines the calibration accuracy at the high end of the scale (lower numbers are usually more difficult to measure accurately), and the audit does not check repeatability. Consistently 25 to 30 percent of the analyzers checked fail this simple audit test.

EPA's own limited evaluations have also shown problems. One check on auto exhaust 1/ under nearly ideal conditions showed a 35 percent difference between two different makes of analyzers. This difference resulted in over 10% of the vehicles passing on one brand of analyzer and failing on the other. Another very limited study 6/ suggested that the HC analyzer reading could shift in a little as two hours of operation. Disassembly and cleaning of the optical bench would rectify the problem, but this would hardly be a practical solution in the field.

The data presented would suggest that the state of current analyzers could generate a large amount of invalid test data in an I/M program.

E. Alternatives

Basically the issue of minimum quality analyzer specifications comes down to two alternatives; a) are they needed or b) can we get by without them? If it is concluded that some form of minimum quality is needed, then the mechanisms used to implement that minimum quality specification become a policy issue. Such issues are discussed in Chapter V.

The previous sections suggest that there is a reasonable case for determining that some sort of minimum quality is needed. But, what about the opposite alternative? Are there advantages that could result if minimum specifications were not required.

One possible advantage of not specifying minimum requirements could be that the States would have more flexibility to determine their own needs. Although this option may sound appealing, the practical aspects may not be as desireable as anticipated. First, it is possible that the number of individual analyzer specifications would equal the number of states participating in I/M programs. Practically though, there would probably be sufficient commonality to group the multitude of specifications into maybe 5 or 10 distinct sets of requirements. This assumption is based on the fact that ancilliary requirements of the current New York, New Jersey, and California specifications are sufficiently different, such that they would not allow the interchangeability of analyzers between these States.

This lack of commonality of analysis systems poses two major problems. First, for each set of specifications, the interested manufacturers would have to design a special instrument package or modification package to a

basic system. Because of the assumed number of specifications, the market share would tend to be minimal. Under these conditions, most manufacturers tend to make a single production run of those instruments, and then move on to the next set of specifications. Such is currently the case for the recently purchases New Jersey analyzers.

An immediate problem also occurs when these assumed 5-10 designs must be designed and manufactured all within the same time frame in order to meet current State implementation dates. Possibly, the industry can accomodate such an intensive effort, but the multiple efforts place a large burden on the industry. Consider, for instance, that multiple specifications would tend to expand the manufacturers' analyzer product line from one to possibly 10 analyzer configurations. That means 10 different sets of documentation, 10 different lines to stock in inventory, possibly 10 different qualification requirements and testing, distribution problems, etc. The magnification of manufacturing and distribution problems potentially affects each manufacturer involved in supplying this equipment. In the end, the user (State, contractor, or service center) pays for this multiplicity of effort.

Once in the field, a second set of long term problems begin to show up. Because of the assumed single production run, duplicates or additional analyzers needed at a later date may force the customer (State or service center) to wait for the next production run. The next production run may not occur if there is not sufficient demand. If a production run does occur, it would be reasonable to assume that the volume would be less than the original run, possibly causing an increase in the retail price.

Another long term problem is the availability of spare parts for these different systems. It is reasonable to expect that it would be profitable for the manufacturers to maintain spare parts for the larger volume versions. Without other influences, it may be less profitable for the manufacturers to maintain as large an inventory (or even one at all) of spare parts for the smaller volume versions. The user of the smaller volume versions ultimately will pay for these factors through either forced inventory requirements, longer repair times, or possibly the inability to repair the unit at all, thus, necessitating the purchase of a new unit.

F. Precedents

Finally, before considering recommendations on the issue of minimum specifications it is always useful to see how others have approached this issue. For instance, some states have established minimum quality requirements for inspection analyzers. Both California and New Jersey have had vehicle inspection programs for at least 5 years. California's initial program covered only change-of-ownership inspection, but even so, California issued minimum specifications known as the "BAR 74 Specifications" (Bureau of Automotive Repair). The BAR 74 specifications included minimum verification testing. California has exhibited a further need for minimum specifications by implementing a more stringent set of specifications known as "BAR 80". New Jersey, on the other hand, has not published a set of specifications like either the BAR 74 or the BAR 80, however New Jersey does publish a list of acceptable analysis systems that may be used. An analyzer is only placed

on the New Jersey list after it is tested and judged acceptable by the State. Without extensive research, it would be difficult to know the exact reasons why these states found it necessary to implement minimum acceptance criteria. One can suspect that the reasons have some relationship to the consequences of bad data, especially on the equality and fairness to the vehicle owners, or in a word -- consumer protection.

Precedent is also established in the area of ambient air monitoring. Minimum instrument specifications have been formally established by EPA, and manufacturers must qualify their equipment through extensive equivalency testing.

G. Conclusions and Recommendations

Probably the most important aspects of the issue of minimum analyzer specifications are consumer protection and the ability to judge the effectiveness of the individual I/M programs in a fair and equitable manner. From the information available, the current analyzers do not provide sufficient confidence that the consumer will be protected. Without outside influences, it is doubtful that this situation will improve. Therefore, one is left with the conclusion that some sort of minimum requirement is justified. The staff also recommends that to be equitable such minimum requirements should be uniform.

Adoption of minimum quality analyzer specifications presents some very practical problems. The specification must provide data that is sufficiently valid; yet at the same time, the specifications must be achievable within the constraints of technology and leadtime. Another practical problem associated with new specifications is that some states have in place less stringent existing requirements. How should equipment purchased under these existing state guidelines in good faith be considered? Finally, what are the best ways to implement the specifications recommended by EPA?

None of these practical questions can be answered, however, without first determining what the exact EPA recommended specifications should be. In the succeeding chapters, the approach used to determine the exact specifications, and the implications that those specifications may have on I/M programs, will be discussed. Recommendations on these issues will be presented, followed by the exact specifications and testing procedures that can be used to verify compliance with these specifications.

IV. The Inspection Analyzer

A. Introduction

The process of obtaining valid emission measurements involves two critical elements --- the equipment and the operation of the equipment. Many technical factors affect the ability of the equipment to measure accurately even when the equipment is new. Other factors affect the ability of the equipment to maintain accurate measurements with age. Certain practices in the operation of the equipment affect the validity of the data as well.

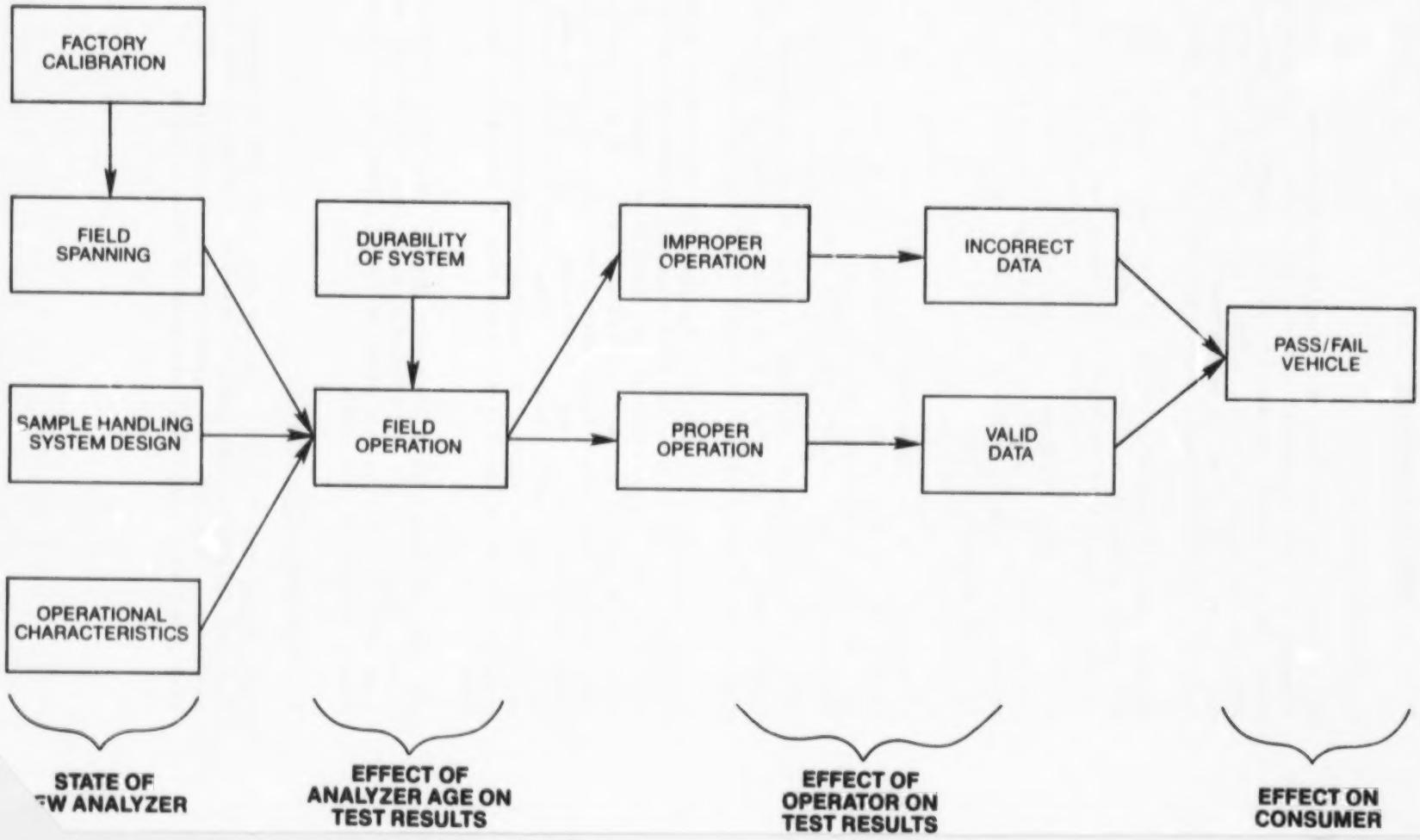
Because the I/M emission check is less sophisticated than the federal driving cycle compliance checks, it might be expected that the requirements necessary to achieve acceptable accuracy and variability with I/M analysis systems would be less sophisticated than those used in the laboratory. To some extent this statement is true, but it is not totally true. Consider for instance, the laboratory analyzers are operated by trained and skilled technicians. These personnel can often spot problems with the equipment even before they happen. Complete engineering departments are constantly checking the laboratory emission values against past values and design goals. Under these conditions, errors in measurement can be detected and eliminated. In a sense, the human mind is adding considerable sophistication to the equipment. The typical I/M analyzer operator generally has not had the training or experience of laboratory technicians and engineers. This training problem is compounded even further in decentralized I/M programs. Mechanics in a repair shop just cannot be required to understand the gamut of measurement problems. Even though mechanics must by necessity become familiar with the I/M equipment, there is an economic incentive to direct their technical skill toward repairing vehicles.

Another significant difference between the laboratory analyzer and the I/M inspection analyzer is the environmental operating conditions. Laboratory analyzers are never operated in hostile environments. They are generally operated in heated and air conditioned buildings with humidity control. I/M programs, on the other hand, expect analyzers to operate from California to Massachusetts, from Texas to Wisconsin, and from summer to winter in a variety of enclosures ranging from rain and wind shelters to permanent structures. This variety of hostile environmental conditions places a much greater burden on an I/M analyzer than a laboratory analyzer ever encounters.

The lack of measurement savvy by the I/M analyzer operator, and the significant variation in environmental operating conditions are just two among many reasons that would suggest an I/M analyzer should be more sophisticated than a laboratory instrument.

B. Measurement Error Sources

Identifying the specific factors for both the equipment and the operator that can influence data quality involves looking at the broad aspects of the measurement process, and assessing the interactions between them. Figure IV-1 provides a simplified overview of this process.


FACTORY CALIBRATION
FIELD SPANNING
SAMPLE HANDLING SYSTEM DESIGN
OPERATIONAL CHARACTERISTICS
DURABILITY OF SYSTEM
FIELD OPERATION
IMPROPER OPERATION
PROPER OPERATION
INCORRECT DATA
VALID DATA
PASS/FAIL VEHICLE
STATE OF W ANALYZER
EFFECT OF ANALYZER AGE ON TEST RESULTS
EFFECT OF OPERATOR ON TEST RESULTS
EFFECT ON CONSUMER

The following tables list some of the specific factors involved in each of the generalized parameters shown in Figure IV-1. Tables IV-1 through IV-4 deal with a new analyzer, Table IV-5 with durability factors, and Table IV-6 with those factors that are under control of the operator (or owner) of the equipment. Each of these items listed affects the validity of the test data in some manner.

Mathematically combining the listed items with standard statistical techniques allows the estimation of an overall measurement error. In order to evaluate the effect of individual items listed in the following tables, various error percentage values can be selected for each item. In this manner, the capability to accurately measure vehicle emission levels can be determined for several levels of technology or specifications, such as best available, current in-use, BAR 74, ETI, and BAR 80. The effect on measurement error of typical failure modes can also be evaluated.

Table IV-1
Factors Affecting the Factory Calibration Curve

1. Accuracy of
    a) NBS Gases
    b) Calibration Gases.
2. Precision (repeatability) of the Analyzer
3. Hysteresis of the Analyzer
4. Analyzer Resolution

Table IV-2
Factors Affecting Field Spanning

1. Accuracy of Calibration Curve
2. Pressure in the Sample Cell
    a) Altitude
    b) Weather Fronts (barometer)
    c) Ambient Temperature Changes
3. Accuracy of the Span Gas
4. Background Levels (Zero Air)

Table IV-3
Sample Handling System Design Considerations

1. Sample Probe Design
2. System Materials
3. System Flow Path (Sample Cell Pressure Variations)
4. Design and Function of Water Removal Device
5. Particulate Filter Design

Table IV-4
Operational Characteristics

1. Non-Interest Gas Interferences
   a) CO_2
   b) H_2O
   c) NO_2
2. Electrical Interferences
   a) RFI
   b) VHF
   c) Induction
   d) Line Frequency and Voltage Variations
   e) Static Electricity
   f) Ground Loops
   g) Basic Analyzer Noise
3. Contamination
   a) HC Hang-up
   b) Particulate build up
4. Effects of exhaust gas temperature
5. Effects of system leaks
   a) Sample line
   b) Other sample transport components
   c) From filter changing
   d) From water trap
6. Effects of Slow Response Time
7. Effects of HC Analyzer response to different HC compounds in the sample
8. Effects of Probe Dilution
9. Effects of Vehicle Exhaust System Leaks

Table IV-5
Factors Affecting Durability

1. Thermal Cycling Effects on

   a) Sample transport components
   b) Optical Bench components
   c) Electronic components

2. Vibrations and Mechanical Effects on

   a) Optical Bench
   b) Sample Pump
   c) Sample Line
   d) Other Sample System Components
   e) Electronic Components

3. Contamination

   a) Chemical attack on sample transport components (short and long term)
   b) Particulate build-up on Optical Bench windows.
   c) Long term HC Hang-up

4. Spare Parts availability

5. Quality of Spare Parts

6. Quality of Repair Service

Table IV-6
Factors Controlled by the Operator

1. Procedures

   a) Warm-up
   b) Spanning (gas and electrical)
   c) Leak Checking
   d) HC Hang-up check
   e) Reading Test Value

2. Frequency of Checks

   a) Spanning (gas and electrical)
   c) Leak Checking
   d) HC Hang-up check

3. Maintenance

   a) Water trap
   b) Filter changes

4. Purchasing substandard replacement parts or filter elements

5. Tampering

   a) Improper repairs
   b) Intentional

C. Acceptable Measurement Error

One of the first issues that working through the model impresses on one is that no matter what specifications are choosen, some error in the measurement will exist. Therefore, some judgment must be made on the amount of measurement error that is acceptable, and the amount that is not acceptable. Further, this decision must be tentatively made prior to selecting individual specifications. Determining a tentative tolerance allows trade-offs between the individual specifications at that given level of error which can be evaluated against practicality and cost. Finally, after the best combination of individual specifications is evaluated, a judgment must be made to ascertain if that level of accuracy is worth the cost.

Data presented in the previous chapters suggest that the current error in measuring emissions could be around ±35%. Additional data from the NHSTA study 2/ shows that a one standard deviation of the ability of multiple analyzers to read calibration gas is around 15 percent. Loosely translated this means that approximately 68% of all analyzers could read calibration gas within ±15% of its actual concentration (32% would be greater than ±15%).

The model (Figure IV-1) shows that the ability to read calibration gas does not guarantee an accurate emission result. Using a 5% calibration curve and rather typical individual specifications (i.e. ETI, BAR 74, in-use, etc.),

the model computes measurement accuracies in the 25 to 35 percent range. Using best technology, it might be possible to obtain better than ±10 percent measurement accuracy. Evaluating failure modes, the measurement errors could exceed 50 percent.

Considering the data, it was our judgment that a ±10 to ±20 error would be a desirable goal. The model predicted that in order to achieve this goal the analyzer must be able to read calibration gas to within ±5 percent. The remainder of the error band would be taken up by trade-offs in other components.

D. Discussion of Current Specifications and Alternatives

In the determination of a set of specifications, the ability of other published specifications to meet the design measurement goals must be addressed. If some other published specification would be able to achieve the necessary measurement accuracy, it would probably be far easier, or at least expedient to adopt those other specifications than to develop completely new specifications. Based on these assumptions the more realistic alternatives for State minimum analyzer specifications are:

Alternative 1:	Adopt the BAR 80 Specifications
Alternative 2:	Adopt the ETI Recommendations
Alternative 3:	Adopt a modified version of alternatives 1 or 2
Alternative 4:	Develop a New Specification

During evaluation of these alternatives, a problem arose in the ability to interpret and compare existing specifications such as the BAR 80 and ETI. The difficulty centered around the fact that these specifications did not include detailed evaluation and acceptance test procedures. In all fairness, the BAR 80 specifications do include acceptance guidelines, but in our judgment many of the BAR 80 guidelines do not contain sufficient details to insure consistant interpretations. This difficulty has also been highlighted by manufacturers attempting to certify analyzers to the BAR 80 specifications.

This confusion in interpretation affects the basic ability to evaluate the analysis systems, and their potential compliance with the design goals. If one cannot accurately determine the capability of a system, then what value are the individual specifications? In EPA's judgment, the inclusion of specific verification procedures is nearly as important as the specific parameter values chosen, and it is important that such procedures be part of any specification.

Even though the more specific evaluation procedures were lacking, an attempt to evaluate the first two alternatives for sources of error (see figure IV-1) was made. This comparison indicated that these specifications addressed the condition of new analyzers, and to some extent the durability of those analyzers, but neither of the specifications dealt to any degree with the effects of the operator's actions. Table IV-6 lists the various actions controlled by the operator that affect measurement accuracy. Table IV-7 details the potential effects of some of these actions. Clearly, operator actions significantly affect the ability of the analyzer system to achieve the design goal of 10 to 20 percent measurement accuracy.

Table IV-7
Incremental Error Due to Operator Actions

	*** Normal Operation ***		*** Failure Modes ***	
	Optimum	Acceptable Maximum	Typical	Worst Case
Field Spanning	±1%	±2%	±6-10%	±30-40%
HC Hang-Up	0%	±5%	±10-30%	+100/(-70)%
Leak Checking	0%	-3%	(-20)-(-50)%	-100%
Reading Test Value	0%	±2%	±10%	±20%

Considering the original question of "can other specifications achieve the design goals for measurement accuracy?", our judgment is that without modifications to those documents to control or account for operator errors, it would be extremely difficult for those specifications to assure that the design goals for measurement accuracy could be maintained. Modifying either the BAR 80 specification, or the ETI Recommentaions to include both evaluation test procedures and operator errors would be a substantial modification to those documents.

Of the alternatives listed, it was determined that a new specification would best integrate the evaluation test procedures, equipment requirements, and operator control requirements. The first draft of these new specifications, which was sent to the analyzer manufacturers for comment, included slightly more stringent performance specifications than BAR 80, and on-board gas spanning, traceability of gases to NBS, and control of operator practices (both procedures and frequency).

Comments on the stringency of the performance specifications were not major. The modifications that have been made to specific performance specifications should alleviate most concerns expressed by the manufacturers. The source of the most vociferous comments were those on techniques to control the operator's actions.

In response to those comments on control of the operator's actions, the causes of analysis error due to the operator were again reviewed. The two main causes for these errors are failure to perform the checks on a frequent basis, and failure to perform the checks properly. The basic alternatives to solve the operator problem are: 1) make the operator responsible (i.e., manual control), or 2) make the machine responsible (i.e., computer control).

Placing responsibility on the operator (or owner) generally means that log books for each and every operation would be maintained to not only help insure compliance in frequency and procedure, but to allow the user to

identify trends in analyzer operation. The maintenance and review of the data implies that the owner will take the time to perform such functions. A slightly less time consuming compromise (for the owner) would place the burden of searching for trends in the log book on a State Auditor.

Placing the responsibility for preventing failure modes on the machine generally requires an on-board microprocessor for internal self-management. Such systems are usually called computer controlled analyzers. The computer controlled analyzer would not totally alleviate the operator from responsibility, but through computer prompting the operator to perform certain checks, and computer analysis of the results, the necessity for maintaining a log book would diminish. Further, the computer system could be designed to be self-policing, could spot trends, and prevent the operator from using the analyzer if the results of any of the various checks exceeded the specified limits.

The initial trade-off between these two basic alternatives is operator time in performing the necessary checks including the log book maintenance, versus the cost of the computer based analyzer. The two basic alternatives represent the extremes between manual control and computer control. There are at least two alternatives that bridge the gap between the extremes.

A step between manual and automatic control would deal with the frequency of performing the proper checks. Very simply, a clock function and indicator lights could be added to the manual system. Such a passive system would remind the operator to perform the necessary function on a proper frequency, but nothing else.

A step up from the simple passive indicator system would be an active indicator system that could prevent the analysis system from testing vehicles (i.e., disable printer, drive meter to full scale, etc.) when an indicator light was activated.

Both of the indicator systems rely on the operator to perform the indicated function before resetting the clock functions. The responsibility to perform those functions correctly is still placed on the owner/operator. To that extent neither of the two indicator options offer that much over the completely manual system.

To recap the candidates for adoption as the EPA recommended analyzer specifications:

Alternative 1. 1980 BAR Specifications
Alternative 2. ETI Recommendations
Alternative 3. Modified BAR or ETI
Alternative 4. EPA Recommendations
- a) Manual Operation
- b) Manual Operation w/passive indicator system
- c) Manual Operation w/active indicator system
- d) Computer Operation

Although the previous discussion concluded that the first three alternatives will not achieve the desired measurement accuracy, and that alternative 4b) and 4c) may not offer that much, a final recommendation must include the considerations presented in the following sections.

E. Cost of Alternatives

In the previous section, four basic alternatives for minimum specifications were suggested. Although one must view the total inspection costs from a broad perspective, it is also important to evaluate the possible impact that the various equipment specifications may have on retail prices of the equipment.

In order to equitably judge possible cost differences between the alternatives, a reference framework was selected. For this reference, the 1974 BAR (California Bureau of Automotive Repair) analyzer specification was chosen.

Another aspect to consider is the effect of inflation on analyzer costs. In 1974 most analyzers meeting the BAR 74 specifications cost around $2000 to $2500. Table IV-8 indicates how these costs for a basic analyzer have escalated with the Consumer Price Index (CPI). Although the CPI represents a composite annual increase, and the analyzer manufacturing industries' retail prices may deviate from the CPI for a given year, the overall trend is reasonably accurate. For instance, the current price (May 1980) for a Sun EPA 75 analyzer (which meets the BAR 74 specifications) is around $3400. This price falls between the two mid-1980 costs shown in Table IV-8.

Table IV-8

Inflation Effect on Analyzer Cost
(BAR 74)

Year	CPI*	CPI Cost
74	New Cost	2000 2500
75	7.0	2140 2675
76	4.8	2243 2803
77	6.8	2395 2994
78	9.0	2611 3263
79	13.3	2958 3698
80 (June)	(3.8+)	(3070) (3838)
80 (Dec)	14.6++	3390 4237
81	10**	3729 4661
82	9**	4064 5081

* Composite Consumer Price Index from Bureau of Labor Statistics (Jan. to Dec. values)
** Estimated annual inflation rate
\+ Estimated 1.25% per month for 6 months
++ Estimated 1.25% per month for 12 months

The evaluation of the technical alternatives starts with the alternative expected to have the least technological impact and progresses to the alternatives expected to have the greatest technological impact.

The ETI recommendations were judged to have the least impact. In many respects, the ETI recommendations are similar in stringency to the BAR 74 specifications even though the assumed intent of the ETI specifications was to provide an alternative to the BAR 80 specifications. Based on the stringency of the ETI recommendations, and the current technological state of the industry, if the ETI recommendations were adopted as minimum specifications, only minor changes to current analyzers (BAR 74) resulting in effectively no retail price change (due to technology improvements) would be expected. Even though no retail price increases are foreseen due to technology, the cost of such analyzers would increase due to inflation.

The next specification in order of increasing stringency is the BAR 80 specifications. These specifications include more stringent specifications than the ETI recommendations and provide acceptance criteria. BAR 80 does not, however, include evaluation test procedures or specifications to control the operator's actions.

The retail cost of the first analyzer to pass the BAR 80 specifications is in the range of $4100 to $4300. If we use 1979 or mid-1980 data from Table IV-8, a BAR 74 analyzer costs between roughly $3000 and $3750. Using this range and an average price of $4200 for the BAR 80 analyzer, the improved technology of the BAR 80 specifications (over BAR 74) represents an increase in retail cost between $450 and $1200. Using this price differential, we would esimate BAR 80 analyzers will be in the $3750 to $4950 price range (1980 dollars).

Although the third alternative, modification to either BAR 80 specifications or the ETI recommendations could represent an improvement in analyzer quality, such modifications would effectively be an entirely new specification, and thus this option was not evaluated separately.

The options investigated under the fourth alternative (the new specification) included manual operation, manual operation with a passive reminder, manual operation with an active reminder (lock out), and computer operation. In order to evaluate these options and allocate costs, a rough idea of the potential market is needed. Based on the number of States beginning I/M programs in the next few years, it is estimated that somewhere around 25,000 inspection analyzers will be needed in the next 5 years. If 5 analyzer manufacturers* actively market inspection analyzers, by assuming equal market shares, each manufacturer would be able to spread development cost across 5000 analyzers. If fewer manufacturers entered the market, the development cost per analyzer would be cheaper. Further, some manufacturers

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* Written comments from an analyzer manufacturer on the draft of the EPA specifications specifically suggested only 5 analyzer manufacturers may actively pursue the inspection analyzer market. It is assumed that the remaining manufacturers would continue to market repair analyzers.

might allocate some of the development costs to improvements in their vehicle repair analyzers. For the purposes of comparison, however, we will use the 5000 unit figure.

For the completely manually operated analyzer, we would expect some developmental and modification costs over and above that completed for the BAR 80 systems. These modification costs would be as high as $100,000**, but spread across 5000 units, this cost would only be $20 per unit. Using a 3 to 1 retail price mark-up, modification costs would increase the retail cost of an analyzer by $60 per unit.

Final accreditation and verification cost increase (due to the improved verification testing) on three units represents roughly a $5000 increase over the BAR 80 procedures (BAR 80 accreditation currently costs around $10,000). Using the same costing procedure, a more thorough verification testing process increases the cost of the analyzer around $3.

Estimated retail hardware costs are listed in Table IV-9. These improvements not only improve the basic analyzer over the BAR 80 analyzer, but they are also directed at improving the operator's actions which are not addressed in the BAR 80 specifications. Even so, the manual EPA system will place the responsibility for those actions on the operator.

The total cost for these improvements is around $720 (Figure IV-9) over a BAR 80 unit. Based on this price increase and the estimated price range of the BAR 80 analyzers, we would estimate the cost of the manually operated EPA specification analyzer would be in the $4470 to $5670 price range (1980 dollars). Since these improvements would not require a redesign of BAR 80 optical bench, we would estimate the lead time for the improved analyzer to be around 0 to 9 months.

** Based on informal conversations with industry representatives and comments on the draft EPA specifications.

Table IV-9

Estimated Retail Cost Increase*
EPA Recommended Inspection Analyzer
Manually Operated Version

Item	Cost Increase
a) Development	$60
b) Improved Verification Testing	$3
c) Gas Spanning System Improvements	$150
d) Detector Improvements	$210
e) Signal Conditioning Improvements	$80
f) Leak Check and HC Hang-up Systems	$120
g) Sample Cell Heater or Electronic Compensation	$100
	$723

* Cost increase over BAR 80 due to EPA improvements.

The next option on the basic manual system would be the passive reminder or indicator system. This system would include a clock function, indicator lights, and reset buttons. No interfacing (other than the sample read to HC hang-up light) would be required. Therefore, the passive system could be a stand alone system attached to the basic analyzer. We estimate the retail cost of this option to be between $300 to $500. Lead time is expected to be 3 to 9 months.

More sophisticated than the passive indicator system would be the active reminder system. Such a system would be similar to the passive system, but would require substantial interfacing with the analyzer in order to lock out or prevent vehicle testing when one of the reminder lights were activated. Resetting the reminder system would allow testing to proceed. It is assumed that the operator would perform the necessary functions before resetting the system, but the system would not be able to verify that those actions actually had taken place. The cost of this system would probably be around $300 to $500 over the passive system, or about $600 to $1000 over the basic manual system.

The final option investigated was the computer operated system. This option would place more responsibility on the machine for the operator's actions, and in many cases would perform the operations automatically. The development of the microprocessor based computer system including software and hardware programming could cost an additional $300,000 over the basic manual EPA system. Using the previous costing procedures, the development costs would increase the retail price by around $180 (Table IV-10). Final accreditation testing would be about the same as the manual system, and therefore would not result in any additional incremental price increases.

Estimated retail costs of the additional computer hardware is listed in Table IV-10. As indicated by the incremental price increases, interfacing electrical signals between the processor and the analyzer is a significant task. The total cost of adding the computer to the manual analyzer is estimated to be around $1700. This increase in price would place the computer analyzer (without automatic data collection) in the $6175 to $7375 price range. The lead time to place computer analyzers in the field is expected to be around 9 to 18 months. (New York State has contracted with one manufacturer to provide several thousand similar units by the end of 1980).

Table IV-10

Estimated Retail Cost Increase*
Computer Operated EPA Recommended Inspection Analyzer
Computer Operated Version

Item	Cost Increase
a) Development	$180
b) Microprocessor Board	$375
c) Signal Interfacing	$900
d) Basic Printer	$250
	$1705
Options (See Chapter IX)	
a) Automatic Data Collection	$500
b) Additional Printer Capability	$200
c) Anti-Dilution (CO%)	$800
d) Loaded Mode Kit	$900
e) Engine Tachometer (RPM)	$150

* Increase over EPA manual system

Table IV-10 also lists some optional features that one may wish to obtain. The automatic data collection and the expanded printing systems could only be added to the computer analyzer. The other options (anti-dilution, loaded mode kit, tachometer) could be fitted to any of the manual systems as well.

Table IV-11 summarizes the estimated price ranges for the various alternatives. Bear in mind that these direct costs must be evaluated in relation to the overall implementation costs before making a final specification choice. Further, recognize that these estimates are in mid-1980 dollars. If current inflation trends are maintained, the retail price at the time of purchase will most likely be higher than that indicated.

Table IV-11

Comparison of Analyzer Costs
(Mid-1980 dollars)

Specification	Estimated Retail Price Range	Step Increase
BAR 74 and ETI	3000 - 3750	-
BAR 80	3750 - 4950	975
EPA (Manual)	4470 - 5670	720
EPA (Passive)	4770 - 6170	400
EPA (Active)	5070 - 6670	400
EPA (Computer)	6175 - 7375	1705*

* Increase over EPA (Manual)

F. Production Variances and Field Audit Testing

The previous sections in this chapter have dealt with the capability of a single analyzer. If all analyzers in a production line and all analyzers between all manufacturers were identical, testing one analyzer would indicate the quality of all analyzers. Obviously all analyzers are not the same. The intent of a set of specifications is to accomodate the real variences between analyzers, and yet meet the design goals for measurement accuracy. The intent of evaluation testing is to verify that the analyzer design truly meets those specifications. The intent of field audit testing is to spot check certain parameters to assure basic operation and analyzer condition.

The problem is two-fold. One, the audit check assumes that all analyzers met the complete specification criteria when new. Two, practical audit checks are not complete enough to verify that the analyzers are meeting all criteria (otherwise the audit test could be substituted for the evaluation procedures). The missing element is production variation.

There are several avenues to deal with production variation, and overall quality assurance and quality control (QA/AC). All of these approaches deal with testing production analyzers. The analyzer manufacturers claim that any full evaluation testing of production analyzers is unwarranted, that it constitutes re-certification, and that their current production checks are adequate.

EPA disagrees. Many of the problems with analyzers attempting to be certified to the BAR 80 specifications have been production type problems*, even

* Informal contacts with California BAR personnel.

though the certification analyzers are generally specially built pre-production analyzers. If anything, the specially built analyzers should exhibit better quality than production analyzers.

In response to the industry claims that current production checks are adequate — How do they know? Have they procured analyzers from the field and performed proper evaluation test procedures on them? The NHSTA study 2/ suggested that continually repeatable readings tended to lead the operators to believe the units were accurate, when in fact, around 80 percent of the units were inaccurate. The fact is that no one is really evaluating the performance of analyzers in the field. Therefore, if these analyzers were producing bad test data (which the NHSTA study suggests), no one would know.

Fully evaluating a few analyzers in the field might be one means of assuring valid test data. But suppose it was determined that the design or production run truly was bad. The damage would have already been done. Hundreds or thousands of analyzers would already be in the field.

From a practical point, most people would prefer to find out if analyzers leaving the production line were of proper quality. To determine if the analyzer is meeting the specific criteria, it must be tested. Testing more analyzers means more production costs. The number of additional analyzers tested will depend on the sample plan, which will, in turn, determine how much the QA/QC program will cost the customer.

The QA/QC approach the staff recommends is a compromize which provides reasonable assurance that both the design and production practices of the manufacturer will have been tested. Several other sample plans such as SEA (Selective Enforcement Audit) or full recertification each year were investigated. However, to save cost, and to some extent overcome industry resistance to continual, periodic production checks, production line testing is limited to 3 units selected randomly from the first 20 produced. The recommended QA/QC procedures found in Table IV-12 are expected to increase the retail price around $20 per unit.

To supplement the QA/QC plans, (which does not completely assure that production problems will not occur after the first 20 units) thorough field evaluations by State auditors during their periodic audits is recommended. ETI and EPA are working on guidelines for these audit procedures, which will be able to detect most production errors, but also should be able to detect random equipment problems as well as other problems due to wear, abuse, etc. These guidelines will be published as soon as they are finalized.

Table IV-12

Recommended Qualification Program

I. Pre-Production

1. The manufacturer may receive a preliminary accreditation, valid for six(6) months, by providing a publically released report which demonstrates that at least one pre-production unit has passed all evaluation tests.

II. Initial Production QA/QC

1. The manufacturer shall also select, in a random manner, three of the first 20 production units, and all three shall receive all evaluation tests.

2. If two of the three units pass all evaluation tests, the instrument shall receive full accreditation valid for a period of three years from the date the first unit was produced.

3. If two or more units fail the evaluation tests, corrections to the design and/or production must be made, and three additional units selected from a new or current production run. Two of these three must pass all evaluation tests.

4. All units covered by a preliminary accreditation and produced prior to the production run in which full accreditation is received shall be required to incorporate the necessary design and/or production fixes.

III. Subsequent Production QA/QC

The accreditation may be renewed for a three year period at any time by passing all evaluation tests on two of three units selected randomly from a production run of 20.

IV. QA/QC Testing Criteria

1. Two(2) of the three(3) production units must pass with no design or random failures.

2. A design failure is defined as a failure to meet the evaluation procedure criteria.

3. A random failure is defined as the failure of a standard part in the system (i.e. pump, electrical resistor, etc.) where improved procurement specification, assembly technique, or pre-assembly QC on that part would reduce failures in the field.

4. An infant mortality is defined as the total failure of a part (usually a computer chip or related components) within a short period of time after the unit first receives any electrical power. Infant mortality failures must have sufficient documentation (i.e. published report available to regulatory bodies) to justify why the failure can be attributed as infant mortality and not minor design failure. Infant mortality failure is not classified as an analyzer failure if the failure would be obvious in the field. After repairs, those tests that might be affected by the repairs must be rerun.

5. Random failures must have sufficient documentation (i.e. published report available to regulatory bodies) to justify why the failure can be attributed as a random failure and not minor design failure. Random failures may be repaired on pre-production units only. A condition to allow the repair of the pre-production analyzer is the development of a plan (where necessary) to prevent the specific type of failure in production units. After repairs, those tests that might be affected by the repairs should be rerun.

G. Conclusions and Recommendations

This chapter began by focusing on two aspects of measurement -- the equipment and the operation of that equipment, how those variables affect the validity of the measured data, and the fact that some measurement error must be tolerated. The amount of total measurement error that can be tolerated determines the real bottom line on the technical aspects of any set of analyzer specifications. This bottom line also provides a yardstick with which to compare different specifications.

Technical consideration is not the only consideration in the selection of analyzer specifications. Both the initial cost of the analyzers, and the availability of the analyzers must also be considered as well as the overall program cost and the inspection fee structure.

On the issue of total measurement error, simple calibration curve accuracy has been noted to be considerably different than total measurement accuracy. Our technical judgement is that a total measurement error of ±15 to ±20 percent of the true value is probably sufficient, and would be considered valid data for an inspection program. Measurement errors of ±10 to ±15 percent of the true value would be much more desirable. Achievement of either of these measurement goals would require a calibration curve accuracy of ±5 percent of true value or better. The error difference between the 5 percent and the 10 to 15 or the 15 to 20 percent figures is taken up by errors in other parts of the system, or by errors due to the operator's actions.

Evaluating current analyzer specifications (BAR 80, ETI, and other State programs), indicates that these specifications will not be able to assure even ±20 percent true measurement accuracy. The BAR 80 specification comes the closest to the 20 percent figure, and BAR 80 analyzers might even be able to meet that figure if operated correctly. But, BAR 80 does not include sufficient specifications to insure proper operation in the field, and more fundamentally, the BAR 80 lacks sufficient definition of the verification procedures necessary to identify if the 20 percent figure would be truly met. Based on an overall evaluation of other specifications, EPA has developed a set of recommended analyzer specifications which will provide measurement accuracies better than 20 percent. The recommendations are found in Chapter VI through XI.

Four options on the EPA specifications -- manual control, manual control with a passive reminder system, manual control with an active reminder system, and a computer controlled system were evaluated. Based on technical considerations, the completely manual control is recommended as minimum specifications for all inspections in centralized inspection programs and for those decentralized programs that may have constraints that would prevent those programs from exercising other options. A passive reminder system added to the basic manually operated analyzer is recommended as an option which the States could select for those decentralized applications using the manual system.

The active reminder system is not recommended on technical grounds because it does not deal with improvements in the operator's actions, but only with the improvement in the frequency of those actions. Secondly, the complexity and the cost of the active reminder system approaches that of a computer operated system. Thus, the cost effectiveness of the active reminder system is much less desirable.

On a technical basis, the computer operated inspection analyzer is recommended for all decentralized programs, and for inspection in centralized programs where operator training and technical management oversight is limited by budget or other constraints. The computer operated analyzer is also recommended for those centralized programs that may have rather remote testing lanes with limited support facilities at those remote locations.

These technical recommendations (stated above) must be reconciled with the other factors of cost and leadtime. Previous discussions on cost have indicated that the average mid-1980 price for BAR 74 analyzers is around $3400. Estimated average price (Table IV-11) for BAR 80 analyzers is around $4350, for the EPA manual system around $5100, and for the EPA computer system around $6800. Production audit testing is expected to add about $20 to the cost of the systems.

For those states implementing centralized inspection lanes, these analyzer costs are very minor compared with the overall costs of setting-up and operating the inspection lanes. However, for those states implementing decentralized programs, the cost of the analyzer in relation to the overall program costs must be considered.

A critical consideration for States implementing decentralized programs is the determination and allocation of the inspection fee schedule. For instance, is a portion of the inspection fee to be allocated to subsidize 100 percent of the cost of the analyzer, 50 percent of the cost of the analyzer, or is the owner expected to completely subsidize the cost of the analyzer as a "cost of doing business"? The same questions must be asked on the subjects of labor costs, and recurring equipment and maintenance costs.

Table IV-15 illustrates direct analyzer costs to the owner. The yearly amortization would represent the owner's average out of pocket expenses for various initial costs. The yearly amortized cost would also represent the yearly costs if the I/M fee were not meant to subsidize the purchase of the analyzer. The other columns represent the average payback or rebate per vehicle for two different inspection fee subsidy rates.

A governing factor on whether the inspection fee subsidizes the purchase of analyzers is whether the service center recoupes the inspection labor costs. Table IV-16 indicates average inspection costs (one free reinspection) at various labor rates, and with various inspection times. The inspection labor efforts may involve moving the vehicle into the bay, setting up the equipment, testing the vehicle, and paper work. It can be seen from this table and Table IV-15 that the inspection time factor is probably more important than the analyzer cost.

Table IV-13

Analyzer Costs*
(5 years)

Initial Analyzer Cost	Yearly Amortization	Average Cost per Vehicle	
		50% Fee Allocation	100% Fee Allocation
$3500	923.29	$ .62	1.23
$4500	1187.09	$ .79	1.58
$5500	1450.89	$ .97	1.93
$6500	1714.68	$1.14	2.28
$7500	1978.48	$1.32	2.63
$8500	2242.28	$1.49	2.98
$9500	2506.08	$1.67	3.33

* Assumptions

a) Average Annual Auto Population = 800,000
b) Number of Inspection Stations = 1064
c) Annual Interest Rate (INT) = 10%
d) Program Length (PRL) = 5 years

e) Amortization = $\frac{INT\ (1 + INT)^{PRL}}{(1 + INT)^{PRL} - 1} = .2638$

Table IV-14

Average Inspection Labor Cost per Vehicle*
(5 year period)

Inspection Time	$20/hr	$25/hr	$30/hr	$35/hr
5 minutes (.083 hours)	$2.63	$3.29	$3.95	$4.61
10 minutes (.167 hours)	$5.30	$6.63	$7.95	$9.28
15 minutes (.25 hours)	$7.94	$9.92	$11.90	$13.89

* Assumptions

a) Annual Inflation Rate (INF) = 10%
b) Program Length (PRL) = 5 years
c) Stringency Factor (STR) = 30%
d) Inspection and one free Reinspection Labor Costs = (time)(hr rate)(1 + STR)

e) Average Annual Costs w/Inflation = $\frac{\sum_{i=0}^{PRL-1} (1 + INF)^{i}}{PRL} = 1.221$

A recent NHSTA study 3/ on small repair centers (those less than $185,000 gross per year) indicates that the small centers account for around 46 percent of all vehicle repairs, and gross an average of $79,000 per year (1977 dollars). Such repair facilities would be expected to be affected the greatest by the purchase of a new analyzer. If it is assumed that the inspection fee were sufficient to cover the inspection labor, incidental equipment maintenance, and expendible supplies, the largest individual expense by the small service center would be the cost of the analyzer. It is also assumed that these small service centers would only need one analyzer. Using the $79,000 average gross per year, a yearly amortized cost of $2500 for the highest range of costs ($9500) given in Table IV-15 would represent only around 3.3% of the yearly gross income. For an average analyzer retail price of around $6820 (EPA recommended decentralized computer operated inspection analyzer), the amortized cost would represent 2.3% of the average gross. Even if other factors such as inflation, etc. caused the analyzer retail price to rise to $9500, the net effect on the small owner would be an increase in cost of only 1 percent of the average gross income. An expense of 3.3% of one's annual gross is one third of typical inflation rates, and is normally not considered a major expense.

Therefore, even if a very expensive analyzer were used with absolutely no subsidy from the inspection fee, the analyzer would represent only a minor burden on over 77 percent of the vehicle repair industry (50 percent of 46% plus 54%). Cheaper analyzers and analyzer subsidies through the inspection fees would reduce this minor burden even more. Additionally, the expected increase in mandatory I/M repairs would further offset the cost of the analyzer.

Another area that would reduce the expense of the analyzer is income tax credits. For instance depreciation is determined on the cost minus the scrap value divided by depreciation schedule (useful life). Informal contacts with the IRS indicate that a 5 year depreciation schedule would be appropriate if the EPA specifications indicate a 5 year useful life. However, even if a longer depreciation schedule were used, the total benefits would be approximately the same. The scrap value is a little more difficult to estimate because of the large number of variables involved. A range of scrap value between 10 to 50 percent of the new cost seems reasonable. Using an average scrap value of 30 percent and a 5 year depreciation schedule, the yearly depreciation would be approximately $955 for a $6820 analyzer, and $1330 for a $9500 analyzer.

The tax saving would depend on the tax rate. The minimum tax rate could be zero, but such tax rates are not common. The maximum tax rate for incorporated service centers would be 50 percent. Yearly tax savings for the analyzers mentioned would range between $477 and $665 at the 50 percent rate. More typical tax rates for the smaller service centers would probably be between 15 and 25 percent. These tax rates would result in a tax savings in the range of $143 to $239 for the $6820 analyzers, and $200 to $332 for a $9500 analyzer.

During the first year of depreciation additional tax savings can be obtained by applying an investment credit. Investment credits for this type of equipment are generally around 7 percent of the purchase price. In this

case another $477 to $665 could be subtracted from the tax bill in the first year. The sum of the depreciation tax savings (typical tax rates) and the investment credit reduces the first year amortized analyzer cost between 34 and 40 percent (Total tax savings of $620 to $997). Table IV-17 shows typical yearly costs (including tax savings) to purchase a computer analyzer.

Based on this rather limited discussion of economic impacts, it is still concluded that the cost of an inspection analyzer in a decentralized program is not a significant factor in the selection of that analyzer. These economic conclusions would therefore reinforce the previous technical conclusions and recommendations. These final recommendations are restated in Table IV-18. The exact specifications are listed in chapters VI through X of this report. Evaluation procedures are found in Chapter XI. The issue of availability of the equipment is not totally addressed in the recommendations given in Table IV-18. That issue is more affected by the program recommendations, and will be discussed in the next chapter.

Table IV-15
Yearly Costs to
Purchase a Computer Analyzer
(1980 Dollars)

	1st year	2nd-5th year
Analyzer Cost	$6820	-
Ammortized Cost	$1800	$1800
Tax Savings		
- 1st year investment credit	$ 477	-
- Average Depreciation (25% tax rate)	$ 239	$ 239
Yearly Cost (Maintenance and expendible supplies not included)	$1084	$1561

Table IV-16

Recommended Analyzer Applications

CENTRALIZED Inspection Programs

Recommendation: a) EPA specifications, manual operation.

b) For programs with limited operator training and technical management oversite, or with remote facility location and limited support facilities, EPA specifications, computer operation.

DECENTRALIZED Inspection Programs

Recommendation: a) EPA specifications, computer operation.

b) For programs where lead time constraints can not be accomodated, or other constraints prevent selection of the computer operated system, EPA specifications, manual operation.

V. Program Implications

A. Introduction

In the previous chapters, the need for minimum quality analyzer guidelines was discussed. The recommendation that some form of minimum quality was needed is consistent with the Hawkins policy memo of July 17, 1978. 4/ That policy memo stated that States enacting I/M programs must include minimum analyzer specifications as part of those programs. This report provides specific technical details that the staff recommends the States should adopt as their analyzer standards.

If a State adopts the EPA specifications, the State may face certain implementation problems. This chapter deals with those issues, and provides some recommendations.

B. Implementation Considerations

This report recommends state adoption of the EPA instrument specification because it is the only specification which can assure instrumentation that will provide accurate and repeatable emission measurements. For centralized programs, the 0 to 9 month lead time to procure a manual controlled instrument meeting these specifications is compatible with the required program start date of no later than December 31, 1982.

For decentralized programs, EPA strongly recommends that states adopt the EPA computerized analyzer as their minimum specification. This instrument will greatly enhance the quality of inspections, and provide the consumer and state with convenient data on the inspection and effectiveness of their program. The computer operated analyzer will also allow a reduced frequency of state audits of licensed decentralized inspections. Because of the instrument's self-calibration feature, quarterly audits will provide quality assurance equivalent to the otherwise required monthly audits.

Additional lead time to procure instruments meeting the computer operated instrument specification may be required. The impact of lead time on SIP I/M implementation schedules is discussed in a memorandum from EPA's Assistant Administrator of Air, Noise, and Radiation to the Regional Administrators.

C. Implementation Issues

Adoption of a minimum instrument specification, as is required by EPA policy, raises the issue of how to deal with garages that have already purchased an instrument which may not meet the minimum specification. This issue largely applies to decentralized I/M programs, since the impact of substandard instruments in repair facilities in centralized programs is less critical (inaccurate garage readings will conflict with the more accurate inspection lane instrument, putting pressure on the repair facility to correct the deficiency). The staff has developed a suggested timetable to deal with instruments which do not meet specifications. To an extent, the current status of the I/M program (operating versus beginning to implement) affects our suggested approach.

For operating decentralized programs, EPA recommends adoption of the EPA recommended instrument specification discussed in this report as soon as practicable. Upon adoption, all new instrument purchases should be required to meet this specification. The state should also adopt a plan to phase-out old instruments. The recommended approach would require that instruments not meeting the new minimum specification be taken out of inspection service on a date 5 years after the majority of instruments were originally purchased. Five years is the estimated useful life of an I/M instrument. This approach assures that most licensed station operators obtain a fair return on their original investment. If original instrument purchases have been spread out over a period of time, an alternate approach would be to require that no original instrument failing to meet the new specification be used after it has reached 5 years old. This could be verified at the time of the periodic state audit.

These same approaches could be used by states which are not operating yet, but have recently adopted other (non-EPA) instrument specifications. This will allow gradual upgrading of their program. If the upgrade is to the computerized analyzer, reduced resources spent on audits would occur.

Table V-1 presents criteria we recommend for the phase-out of old equipment in favor of the EPA specification.

Table V-1

Recommendation
for
Phase-Out/Phase-In of Analyzers

Recommended Criteria

1. The emission analyzer was in-use prior to the recommended order cut-off date, or the emission analyzer was not ordered after the recommended order cut-off date.

2. The emission analyzer manufacturer does not make a retro-fit kit that would bring the emission analyzer into compliance with the recommended EPA specifications.

3. The emission analyzer meets minimum equipment specifications. These are:

a) The make (i.e. manufacturer), and exact model of emission analyzer must have undergone performance testing and received accredidation under the State of California BAR 74 specifications.

b) Inclusion of BAR 74 emission analyzer components in a larger vehicle diagnostic tester would be permissible provided those components were certified under the BAR 74 specifications. Documentation should be required to verify the similarity of components to the accredited model.

c) Accredidation under BAR 80 specification would automatically be considered as meeting the BAR 74 specifications.

d) If an emission analyzer by make and model has not been accredited under BAR 74, then that analyzer make and model should undergo evaluation testing prior to use as a grandfathered inspection analyzer. A minimum of three analyzers shall be evaluated. All three shall meet or exceed the BAR 74 specifications or the State's published minimum specifications.

References

1/ "Analyzer Comparison; I/M Demonstration on September 6, 1979", EPA Memo, M. Rosenfeld to T. Cackette, December 17, 1979.

2/ "Results of Field Equipment Evaluation", contractor progress report and draft report submitted to NHTSA, February 1980.

3/ "Evaluation of Diagnostic Analysis and Test Equipment for Small Automotive Repair Establishments", A Report to the Congress, July 1978, DOT HS-803 536.

4/ "Inspection/Maintenance Policy", Memo from David G. Hawkins, Assistant Administrator for Air and Waste Management to Regional Administrators, Region I-X, July 17, 1978.

5/ "Vehicle Exhaust Emission Instruments Evaluation", EPA-460/3-77-014, July 1977.

6/ "Instrument Drift of XXX Analyzer" EPA Memo, E.A. Barth to R.C. Stahman, July 20, 1979.

7/ 40 CFR 86 Subpart K and Appendix X, Federal Register, Volume 45, No. 14, Monday, January 21, 1980.

8/ "Decentralized Private Garage I/M Program Cost Calculation Worksheet", EPA Technical Report IMS-006/CS-2, August 1979.